Oceanus

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The Magazine of Marine Science and Policy

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Manganese nodule collage by E. Kevin King, from WHOI photographs. Back Cover: Sulfide sample crosscut by numerous worm tubes. Photo courtesy of U.S. Geological Survey, Menlo Park, California.

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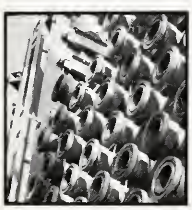

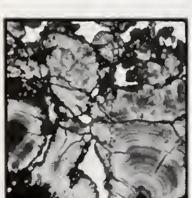

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comment

This issue of *Oceanus* is dedicated to Deep Ocean Mining, a subject that affects the national interest and thus every American citizen. The concerns surrounding seabed mining played a central role in President Reagan's decision this past summer not to sign the Law of the Sea Convention when it is opened for signature in December. Perry Pendley's article, in this issue, indicates that the President's decision was part of a general minerals policy initiated when he first came into office. That policy views seabed minerals as vital to our national security and essential to economic recovery. Joel Clark's article, also in this issue, provides an opposing view.

Prior to the decision not to adopt the Law of the Sea Convention, the Reagan Administration conducted an extensive review of the Treaty's provisions. This review was conducted by James L. Malone, chief of the United States delegation to the sea-law talks. Senator Alan Cranston, Democrat of California, revealed that a draft report prepared by the State Department's Office of the Inspector General had severely criticized Mr. Malone's performance, concluding that he "lacked both the time and the expertise to direct the Law of the Sea Treaty review operations." The draft report found that the State Department's role in the sea-law talks was impeded by Mr. Malone's "bizarre personnel management," and "compounded by uncertain leadership" (*The New York Times,* July 27, 1982). One wonders if the President acted on the basis of a seriously flawed review.

The vigorous dispute over seabed minerals boils down to an ideological confrontation — those viewing the resources of the deep sea as the "common heritage of mankind" (seen by some conservative ideologues as nothing less than global socialism) are pitted against those upholding a "freedom of the seas" approach, whereby the resources of the deep sea are available to those with the knowledge and funds to exploit them. Richard A. Legatski, representing the National Ocean Industries Association (a group of 500 major U.S. companies) told a House hearing on July 27 that the Association strongly supported President Reagan's course of action. He stated that supporters of the treaty had made statements about certain provisions of the Convention that could lead to "misconceptions." He said the United States was not "guaranteed" a permanent seat on the Council of the International Seabed Authority, as the wording of the draft treaty only assured the "largest consumer" of seabed minerals a seat. Legatski added that the technology transfer provisions of the treaty were perhaps the largest problem for private industry. Not only would mining companies be required to share information on mining equipment, he said, but the transfer would extend to such equipment as on-board computers and even satellites relaying mining data.

Conrad G. Welling of Lockheed Missiles and Space Co., Inc., speaking on behalf of the Undersea Mineral Resources Committee of the American Mining Congress (AMC), told the same House committee that the AMC strongly supported the President's position. He stated that, from industry's standpoint, the treaty "had extremely severe defects," among them that the Convention does not provide U.S. firms with assured and nondiscriminatory access, under reasonable terms and conditions, to seabed minerals. He pointed out that the United States would have the "dubious privilege" of paying for 25 percent of the budget of the International Seabed Authority (ISA), plus some of the financing for establishment of the Enterprise, the mining arm of the ISA. Welling said the International Seabed Authority amounted to a government "or huge bureaucracy" with legislative powers (in contrast to the United Nations, which has none) that would be able to approve or deny access to seabed resources over an area exceeding half the globe. "In essence," he said, "the Law of the Sea Treaty would demand that the developed nations of the world supply the know-how and the capital to develop deep-sea mining, but leave the ownership and control of the resources to the developing nations. . . .

"There are those who argue that outside the framework of the Law of the Sea Treaty, deep-sea minerals mining is doomed. If one agrees that the treaty text is deeply flawed, it makes no sense, in my view, to say, 'Yes, the treaty is flawed, but we should join, because that's our only real hope.' I submit that if something is fatally flawed, you don't join it; you seek something that is better."

Welling said he felt that seabed mining is "much more bankable without the treaty" — that future investment would probably come from corporate funds rather than banks — that he knew of no move at the present time by industry to seek government-sponsored risk insurance — and that the American Mining Congress now viewed a Reciprocating States Agreement under the terms of the Deep Seabed Hard Mineral Resources Act of 1980 as the most viable basis for achieving appropriate legal arrangements for deep seabed mining among like-minded nations.

There is always the hope that a later administration will weigh U.S. mining interests (and those of marine science, fisheries, and navigation) differently, and that the U.S. will eventually ratify the treaty. But some observers fear that, by opting not to participate in the work of the treaty's Preparatory Commission, the Reagan Administration is making it extremely difficult for a future administration to adopt the treaty, and for the Senate to eventually "advise and consent."

* * *

The astute reader will notice that *Oceanus* has undergone a major refitting, and that we now have, in addition to our regular thematic material, several new features — a Profile of an oceanographer, a "Concerns" section, Book Reviews, and Letters. These features have been initiated to give you (the reader) a more varied editorial fare. We hope you like it. Let us know what you think.

P.R.R.

Introduction:

Deep Ocean Mining

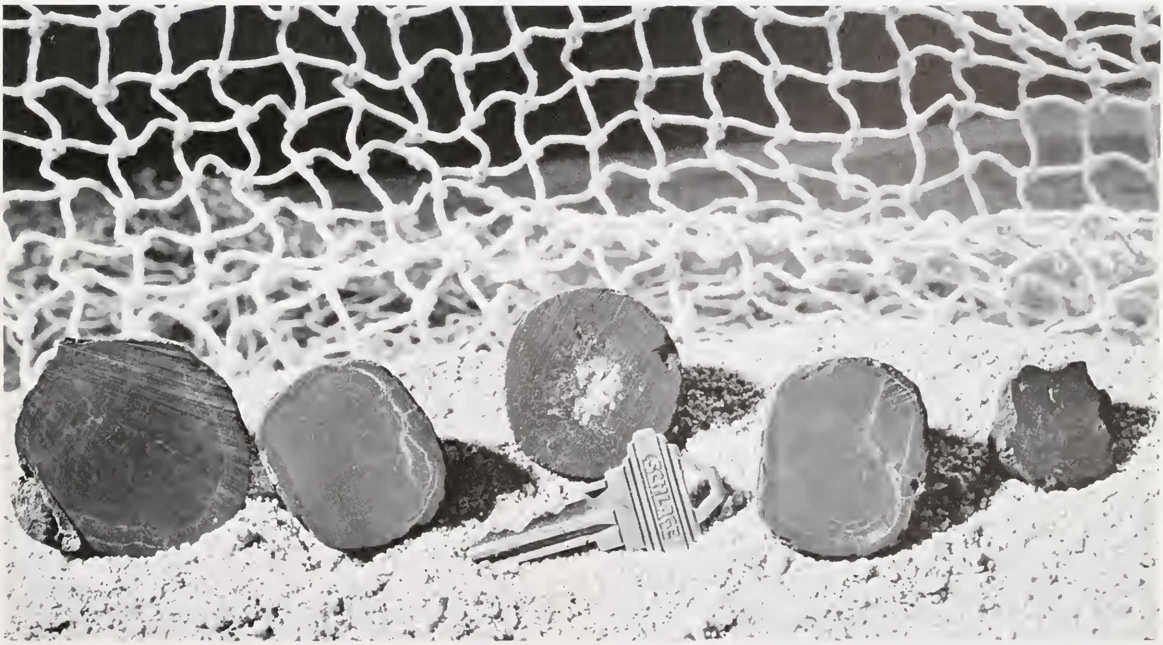
by Robert W. Knecht

The waters of the oceans and the seafloors that underlie them contain vast quantities of minerals. Seawater itself has nearly every known element dissolved within it, but only a few are present in sufficient quantities to make extraction economically feasible. The seafloor is a different matter. For centuries, sand, gravel, phosphorite, tin, and other metals have been profitably mined from beach and shallow-water deposits. In the early 1960s, attention began to turn to the deep seafloor.

By that time, it was clear that large expanses of the deep ocean floor are covered with billions of tons of fist-sized nodules, commonly called "manganese nodules," which conceivably could be mined for the quantities of nickel, cobalt, copper, and manganese they contain. This was of more than passing interest in the United States, since this country has no significant land-based deposits of cobalt or manganese, and only one operating nickel mine (in Oregon). All four metals are designated strategic materials and play vital roles in our industrial economy.

At about the same time, observations in the Red Sea revealed the existence of concentrations of hot saline water on the seafloor at depths of about 2,000 meters. Sediments underlying these pools contain very high concentrations of copper, zinc, and silver. Recent observations indicate that certain aspects of the Red Sea phenomenon also appear at other sea-floor locations in the vicinity of rifts or spreading centers related to diverging tectonic plates.

Recovering minerals efficiently from the deep seafloor is not going to be an easy task. Nodule deposits, for example, typically lie under 4 to 6 kilometers of water. Complex mining machinery would have to work at extremely high pressures. The seafloor in nodule regions is typically composed of



(Photo courtesy of Deepsea Ventures, Inc.)

unconsolidated calcareous or siliceous oozes (shells and skeletons of microscopic creatures that have settled out of the water column), a difficult medium in which to propel mining equipment. And supporting and controlling a string of pipe 4 to 6 kilometers long is clearly a task of some magnitude.

Where and How Much?

Nodules were first discovered during the British *H.M.S. Challenger* Expedition (1872-76). Later observations showed that the deposits are common features on the seafloor, especially in areas with slow sedimentation rates. Deposits can occur as potato-sized or larger lumps, as coatings on rocks, or as extensive pavements. They are composed of hydrated oxides of iron and manganese generally formed around a nucleus, such as a shell, rock, or tooth. Although they are found in all of the world's oceans, both the grade (percentage of metal contained) and the coverage (weight per unit of area) vary greatly from place to place. Nodules in the eastern Pacific, between the Clipperton and Clarion fracture zones for example, seem to contain the highest concentrations of cobalt and nickel. Based on information gleaned from bottom photographs, nodule coverages of up to 100 kilograms per square meter appear to be possible. A full-scale mining operation would require between one and three million tons of nodules per year. It has been estimated that the Clipperton-Clarion area alone could support 25 to 50 mining projects over a 30-year period.

Commercial interest in manganese nodules began in the 1960s with early exploratory work by several U.S. companies. By the mid-1970s, however, these companies and others had formed several international consortia (see page 25) to spread the risk and pool their investments. In the last half-dozen years, the consortia, including an all-French group and an all-Japanese group, have obtained a great quantity of detailed information on the geographic distribution of nodules. In fact, four of them applied for exploration licenses on 10 specific sea-floor sites when applications were first accepted in early 1982 under the Deep Seabed Hard Mineral Resources Act. The exact locations of the sites are confidential, though all are between the Clipperton and Clarion fractures. The consortia are now negotiating among themselves in an attempt to eliminate overlaps.

More than a decade passed between the Red Sea finds and the observation, in 1978, of hot hydrothermal vents discharging dark clouds of precipitating metallic sulfides. Scientists had long suspected this submarine hydrothermal activity, based on analysis of anomalous heat-flow, seismic, and magnetic patterns around spreading centers.

Although the study of sulfide minerals associated with oceanic spreading centers is at an early stage, several interesting sites have been found. Deposits at 12 degrees North on the East Pacific Rise, at 86 degrees East on the Galápagos Rift, and in the Gulf of California's Guaymas Basin all have impressive concentrations of metals. And just last year the U.S. Geological Survey located such deposits off the Oregon coast (see page 42). However, assays indicate a great variability both within and between sites, and until more is known regarding the volume of such deposits and the frequency with which they occur, their commercial potential will be difficult to evaluate.

Status of the Technology

From a technological viewpoint there are five aspects to the deep seabed mining of manganese nodules:

1) the exploration system, for finding an "economic" deposit;
2) the mining collector, for collecting the nodules efficiently;
3) the lift system, for lifting the nodules efficiently;
4) the transport system, for transporting the nodules to shore; and
5) the processing system, for extracting the metals from the ore.

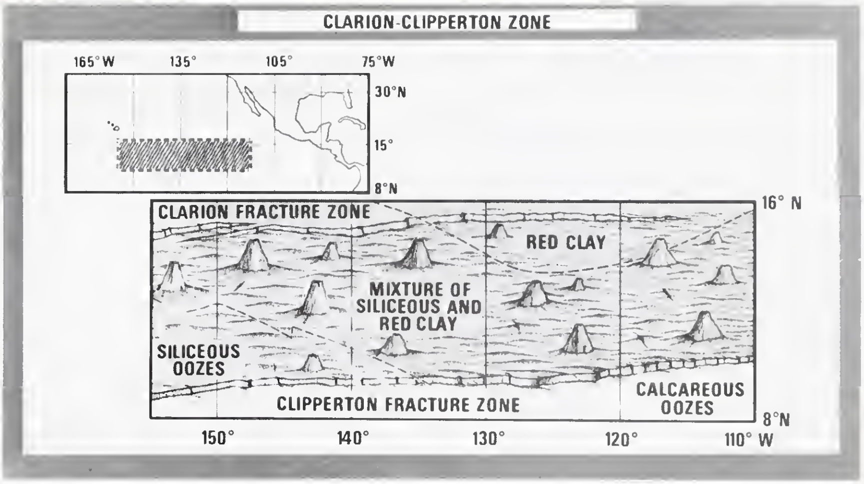
The developers of new technology have focused on the collection system, the lift system, and the processing system. While all the consortia have tested relatively complete systems — albeit at sizes substantially smaller than would be used commercially — a number of rather different approaches to these three elements are being tried.

Mining the Red Sea

The first commercial deep seabed mining may not be for nodules, but for heavy metal-laden sediments at the bottom of the Red Sea. Saudi Arabia and Sudan have formed the Joint Red Sea Commission for the purpose of exploiting deposits beneath the unusual Red Sea Brines, which are hot, salty "ponds" on the Sea's floor. The hot water is discharged onto the seafloor from hydrothermal vents similar to those along the East Pacific Rise. The key difference is that the high salt content of this water makes it dense enough to accumulate in depressions along the bottom. The solution's slow rate of dissipation allows the precipitation of metals brought in by the springs below, forming rich ore deposits.

General contractor for the mining project is Preussag, a large West German mining company. In 1979, this firm brought up 15,000 cubic meters of mud from a depth of 2,200 meters, successfully testing a shipboard system that concentrated the mud, retaining valuable metals. The resulting concentrate was 40 percent zinc, with lesser quantities of silver, copper, and gold, according to Erich Blissenbach, Preussag's Ocean Mining Coordinator. Since the test, the firm has devoted its efforts to environmental studies and the planning of a pilot mining program and processing plant. The pilot operation, scheduled to begin in 1984, would last one year. One hangup, says Blissenbach, is that Preussag engineers have not yet come up with a design for a pump that can withstand the highly corrosive brines for a whole year.

A look at the location and sea-floor topography (simplified) of the area in which four mining consortia have filed claims. Nodules in this zone contain relatively high concentrations of cobalt and nickel. One consortium is considering the construction of a processing plant in the Hawaiian Islands. (Drawing courtesy of Ocean Minerals Company)



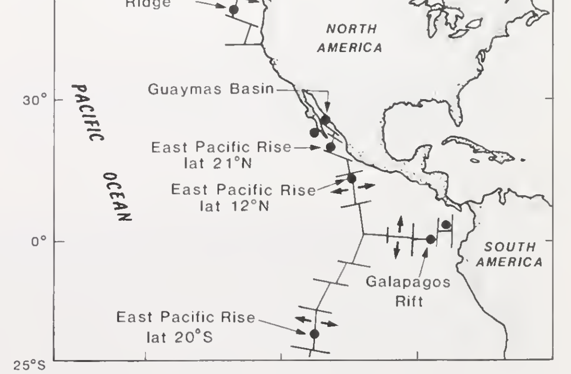
In terms of collectors, the Ocean Minerals Company has recently patented an internally powered mining machine that moves along the seafloor by means of two rotating Archimedes' screws. Other companies have tested passive sled-like devices that are towed along the bottom by a surface ship. Lifting the collected nodules probably would be done by air or hydraulic lift up a long pipe string. The Japanese have tested a system involving a continuous line of buckets on a closed loop of cable, but most observers believe this system is not practical.

The French group is considering more exotic technology. Their concept involves autonomous ore-carrying submarines that would shuttle between the seafloor and a mother surface ship or processing platform. The sub, to collect nodules, would propel itself along the seafloor. Assuming that ongoing feasibility studies are positive, such a system could be field-tested in the mid-1980s.

The system for extracting the metals from the nodules ("processing") will depend on whether three metals (copper, nickel, and cobalt) or four (including manganese) are to be obtained. The three-metal versus four-metal decision will be influenced by projections of the effects of seabed manganese on world manganese prices.* Up to a third of the current U.S. manganese consumption could be produced from one seabed plant. Processing will most likely employ various types of leaching and smelting, involving the use of ammonia or hydrochloric and/or sulfuric acids.

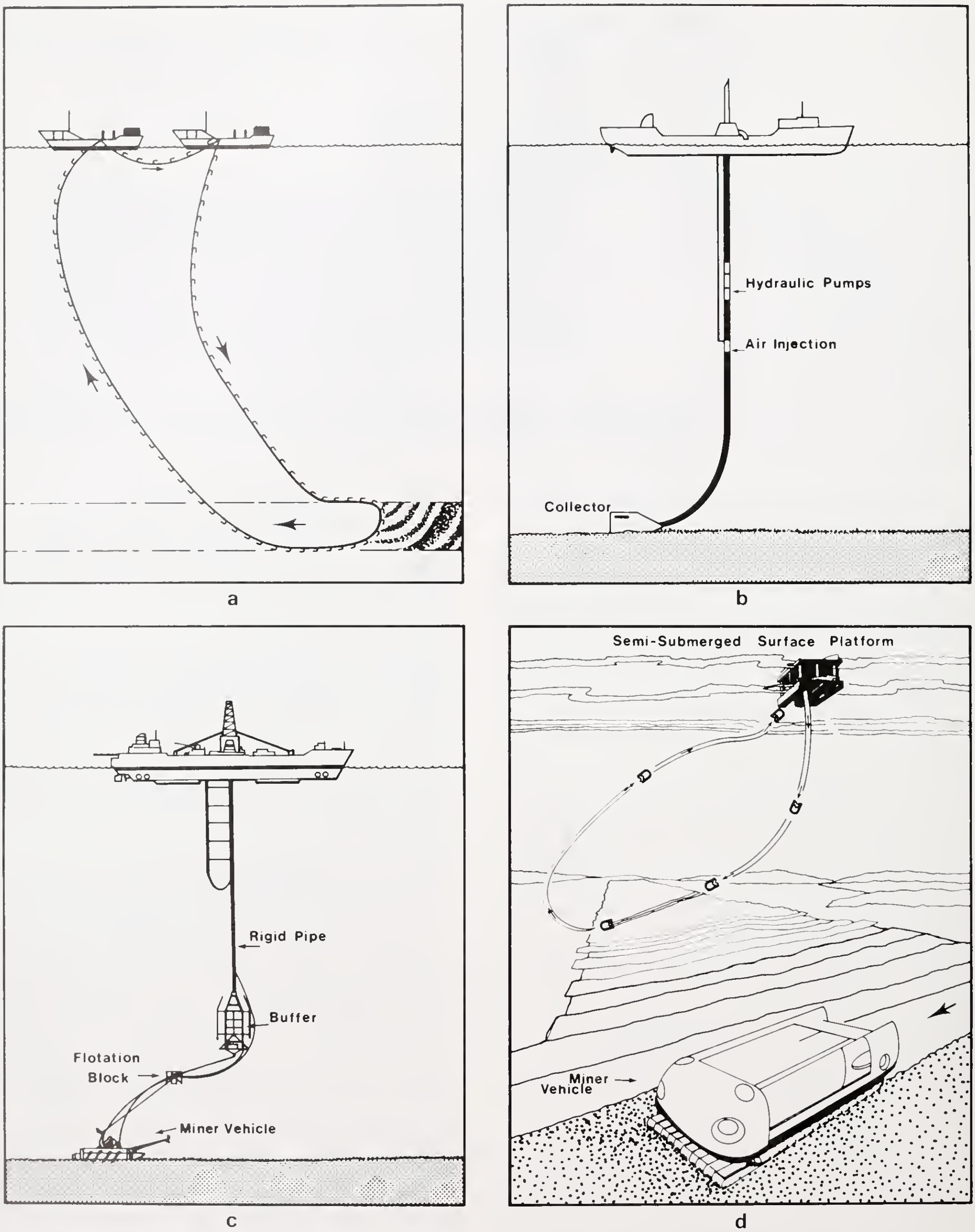
A major problem with seabed mining, as with virtually any mining operation, is the disposal of wastes. In a three-metal process, 97 percent of the material that enters the plant will leave as waste. In a four-metal plant, the waste will amount to about 70 percent of incoming volume. Although the precise form and toxicity of these wastes will depend upon the nature of the processing, it is clear that dealing with the tailings will be an environmental problem the ocean mining industry will have to face. With regard to other such problems, the environmental impacts of ocean mining operations are largely unknown at this point. However, a government research program conducted in 1977-78 in conjunction with small-scale industry tests suggests that these effects probably will be tolerable (see page 31).

While there remain major uncertainties about the cost of scaling up mining systems to commercial

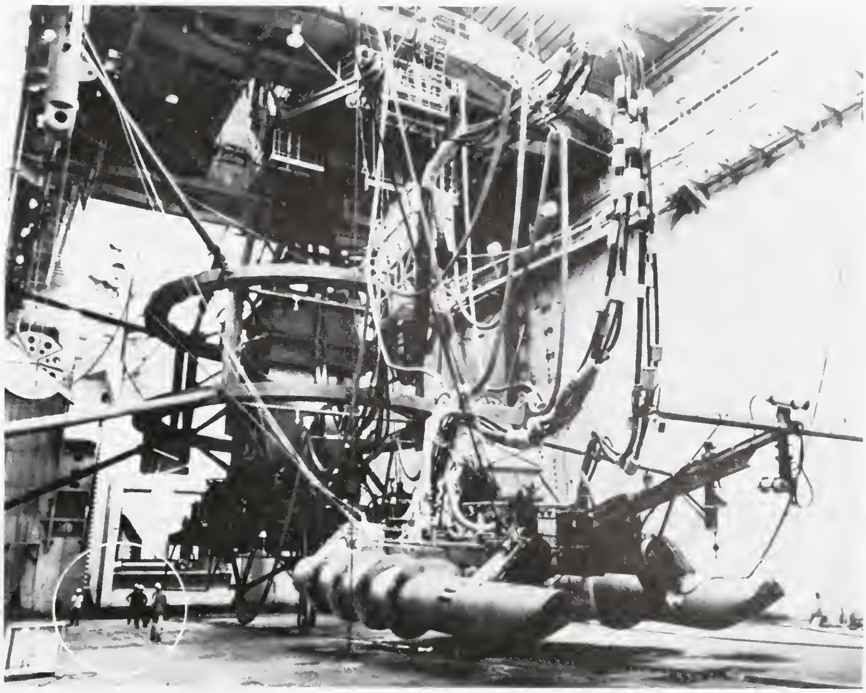


Pacific Ocean spreading centers and locations of massive sulfide deposits. The Juan de Fuca Ridge is off the coast of Washington and Oregon. (Courtesy of U.S. Geological Survey, Menlo Park, California)

*Although manganese is found in only a few places, it is not now in shortage. The most significant land deposits, however, are in Brazil, Australia, Gabon, South Africa, and the Soviet Union. For some companies, direct access to manganese may be an important motivation for mining the seafloor.



Four systems for mining manganese nodules. *The first to be designed was the continuous line bucket system (a), in which a series of dredge buckets is attached to a cable that hangs in a loop from one or two surface ships. As the cable is dragged across the seafloor, it is rotated so that successive buckets scrape nodules off the bottom and bring them to the surface. In recent years, however, the mining industry has shown more interest in automated systems that would use compressed air, pressurized water, or electric pumps. In one such system, the surface vessel would tow a collector along the seafloor (b). In another, patented by the Ocean Minerals Company, a remote-controlled miner vehicle would crawl along the bottom scooping up nodules (c). The vehicle would crush the nodules to a slurry and pump them through a hose to an intermediate station called a buffer, which in turn would feed the slurry to the surface ship through a rigid pipe. The flexible power line and hose could be kept out of the vehicle's path by a flotation block. The futuristic acoustically controlled French system would include a fleet of unmanned, untethered "shuttles," each of which would gather nodules, deposit them at a semisubmersible platform, and swoop down to the seafloor for another load (d).*



The experimental mining device built by Ocean Minerals Company. Weighing about 100 tons, it is approximately 30 feet wide, 45 feet long, and 15 feet high (note men in circle). This model, which scoops up nodules as it crawls along the ocean floor, is only a tenth the size of the final version that would be built for commercial mining. (Photo courtesy of Ocean Minerals Company)

size, the basic technology required for deep-sea mining of manganese nodules exists. However, given the need for a period of three to four years of prototype development and testing and an additional four to five years to design and build a full-scale commercial system (mining machines, lift system, mining and transport ships, and processing plant), it will take an estimated eight to nine years to move from the present stage of development to full commercial operation.

Key Factors in Commercialization

Assuming that there are sea-floor minerals in promising quantities, and that the necessary technology appears to be at hand, what does a decision to develop a commercial seabed mining operation depend on? Or the question can be rephrased: What conditions must be satisfied before investors are willing to lend the $1.5 billion or more that will be needed to build a full-scale system?

The fundamental test is *economic.** During a project's lifetime, the estimated stream of net income from the sale of the metals must provide the prospect of a sufficiently high return on investment (ROI) to attract the necessary funds. Given that a first-generation ocean mining venture with essentially untried technology will be viewed as inherently risky, a higher-than-usual ROI will be required. Estimates put the necessary ROI as high as 25 percent, assuming an acceptable legal-regulatory framework.

To meet the economic test, a mining company must be:

1) confident that its mine site contains a sufficient quantity of nodules of appropriate composition to allow it to produce the requisite output of metals — basically a technical issue.

2) assured of an exclusive right to its mine site for the term of its project, typically 20 to 30 years — basically a legal issue.

3) confident that the costs of production are relatively predictable over the lifetime of the project. These costs can be divided into two kinds: those that relate directly to operations and those attributable to the legal-regulatory system.

4) confident that the net revenues from the sale of the metals will be sufficient to meet the ROI requirement. Revenues will depend directly on the level of metal prices over the lifetime of the project, but also could be affected, under certain circumstances, by the legal-regulatory system.

Perhaps the key economic factor in the commercialization decision is metal prices in the decades ahead. Prices of some of the metals contained in the nodules have been rather volatile in the last 10 to 15 years. Cobalt, for example, ranged from a low of $1.50 a pound in 1964 to a peak price of $25 a pound following the 1978 disturbances in Zaire. The price in mid-1982 was approximately $13 a pound. Recently, metal prices in general have been depressed, reflecting the general state of the world economy. Demand for the metals would be expected to increase with an upturn in the global economy.

*In the case of a government-owned or government-supported mining consortia, other factors, such as strategic mineral access, might well be more important than economic considerations alone.

Metal prices also will be affected by supply. To the extent that land-based mines have to work with poorer and poorer grades of ore, prices of the resultant metals will rise and supplies probably will fall. Note, for example, that copper is now being produced from land-based ores possessing only 0.3 percent of the metal, whereas nodules typically contain at least 1 percent, and some of the recently discovered seabed sulfide ores are as much as 10 percent copper. The entry into the markets of substantial new quantities of seabed-derived metals would have an impact on the prices of these metals, probably bringing about sharply reduced prices in the case of manganese and cobalt.

The Legal-Regulatory Framework

The legal-regulatory framework that ultimately applies to a deep seabed mining operation can and will cut both ways. First and foremost, it is essential to the viability of any seabed mining venture that there be some sort of legal system capable of guaranteeing exclusive rights to a mine site for the lifetime of the project. The adequacy of this security of tenure is of fundamental importance to the potential investor. But with a legal system inevitably come rules and regulations. The reasonableness of those rules and regulations and their stability over time are also matters of prime importance.

Regulations are usually designed to serve several interests. Through them the authority granting the legal rights and guarantees seeks to achieve those of its policy goals that it believes are relevant to the matter at hand. Furthermore, regulations, such as those relating to safety at sea, frequently protect the regulated entity from itself or protect others from the industry's activities. And the regulations often attempt to prevent the regulated industry from shifting costs that are properly borne by it, such as the expense of protecting the environment, to others outside of the project. Given that regulations can both increase costs and decrease revenues, they too are of interest to the potential investor.

Is there now an adequate legal system for deep seabed mining? Does a legally empowered authority, having issued appropriate regulations, stand ready to receive license applications and, after suitable review, issue exclusive rights to a sea-floor mine site? The answer is "yes and no."

To pursue the issue, we must subdivide our geographic area of interest into two regions: that area of seafloor within the limits of national resource jurisdiction and that area of seafloor beyond these limits. For the U.S. continental shelf, the Outer Continental Shelf (OCS) Lands Act, together with the 1958 Geneva Convention on the Continental Shelf, provides fully adequate legal authority and administrative process for all mineral exploitation. For areas of our seabed that are beyond the continental shelf but still within 200 nautical miles of the coast,* a region that might contain important sulfide deposits, the Deep Seabed Hard Minerals Resources Act appears to offer the best prospect of providing the necessary legal framework. Existing regulations, however, would have to be supplemented, and the legislation itself probably would have to be amended slightly.*

As we turn to the region beyond the limits of national resource jurisdiction, a fundamental issue emerges. Who is in the best position to grant exclusive rights to a portion of the deep ocean seafloor well beyond any nation's jurisdiction?

An international entity would seem to be the obvious answer, but prior to 1970 no existing convention or treaty spoke directly to this question. In that year the General Assembly of the United Nations adopted Resolution 2749, declaring the resources of the deep ocean to be "the common heritage of mankind" and, hence, the property of all of us. The U.S. voted for this resolution. A 1969 resolution (2574D), adopted without the support of the U.S. or other potential seabed-mining nations, called for a moratorium on the taking of nodules until a new Law of the Sea (LOS) Treaty establishes a legal-regulatory regime for seabed mining.

On April 30 of this year, a new Law of the Sea Convention was adopted at the United Nations after eight years of difficult negotiations. Even then, largely because of serious problems with the seabed mining regulations (and strong lobbying by the mining industry), the U.S. voted against adoption of the Convention and a number of other industrialized nations abstained. The vote was 130 in favor to 4 against, with 17 abstentions. In early July, President Reagan reinforced the American position with an announcement that the U.S. would not sign the Convention when it is opened for signature in December.

The U.S. had no doubt about the capacity of an international seabed authority, created by a widely supported LOS treaty, to issue legally sound, exclusive rights to seabed mine sites. Indeed, there is no better way to obtain such rights. The Administration did object, however, to certain other aspects of the legal-regulatory framework, including the following provisions:

- *To protect land-based producers of certain metals, limits were to be placed on seabed mineral production.*

- *To help assure benefits to all mankind, decisions would be made on a one-nation, one-vote system and an economically favored international seabed mining company (The Enterprise) would be established that would compete with private-sector mining firms.*

- *To assist The Enterprise, mining companies would be required to sell it their technology.*

- *As part of a review of the operation of the seabed mining regime, a Review Conference, 20*

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*In the opinion of many, 200-nautical-mile exclusive economic zones are becoming customary international law through widespread practice, even before the new Law of the Sea Convention takes effect.

*Amendments to the OCS Lands Act or new exclusive economic zone legislation also could accomplish this purpose.

The Law of the Sea Conference votes on adoption of the Draft Convention — United Nations Headquarters; New York City; April 30, 1982. (Photo courtesy of the United Nations)

years after the start of commercial seabed mining, could revise the legal-regulatory framework in substantial and costly ways without the individual approval of nations affected by such changes.

As early as 1971, the United States considered passing domestic legislation to authorize and regulate deep seabed exploration and exploitation by its citizens. The legislation was alternately advanced or held back, described as "an alternative to an LOS treaty" or as "interim until an LOS treaty comes into force," depending on how our government felt toward the evolving treaty at the moment. In June 1980, the patience of both the U.S. seabed mining industry and its advocates in Congress finally gave out with regard to the LOS treaty process and the U.S. seabed mining legislation was enacted into law.

In the form in which it passed, the legislation was rather evenly balanced between the "alternative to" and "interim" positions. The Carter Administration and its chief LOS negotiator, Elliot Richardson, saw the legislation as filling an interim role until an LOS treaty could come into force. And, in fact, a crucial amendment added just prior to passage ensures that no deep seabed mining for commercial purposes can begin until January 1, 1988, a date thought to be sufficiently distant to allow the treaty to enter into force and, where inconsistent, to supersede the U.S. legislation.

The Reagan Administration, given its negative view of the treaty, has tended to see the domestic legislation as an alternative. Opinions differ, however, on the viability of this approach. Can domestic legislation offer the requisite legal guarantees of security of tenure on a mine site? The legal theory on which the U.S. legislation rests, and that of at least four of the five other nations that have also enacted seabed mining laws (West Germany, Japan, the Soviet Union, Britain, and France), is the 1958 Geneva Convention on the High Seas. Seabed mining is interpreted as an unstated but implied exercise of "freedom of the seas," just like the taking of fish or the laying of cables. As long as an activity does not unreasonably restrict someone else's legitimate use of the high seas, it is seen as legal under international law. However, the recent agreement on a new LOS Convention, one which provides for the first time an explicit international legal-regulatory system for deep seabed mining, will strengthen the resolve of those who argued earlier that the 1969 and 1970 U.N. resolutions alone invalidated this approach.

Four western nations with national legislation (United States, Britain, West Germany, and France) are working to harmonize their programs, with the goal of reciprocal license recognition. Procedures for resolving overlapping mine site claims also are under discussion. To the extent that an agreement on these important matters is reached and actual licensing begins, a modicum of interim legal security for the seabed mining industry will have been created. Already the four nations have coordinated dates for license application procedures. Yet this initial system will apply principally to *exploration* licenses; the extent to which this approach could be enlarged to provide an adequate legal-regulatory framework for the commercial exploitation phase of seabed mining depends very much on the outcome of events in the months ahead.

Outlook

For that portion of the seabed under U.S. control, mining appears likely. The Interior Department recently announced it is prepared to offer leases to companies interested in developing the manganese nodule resources on the Blake Plateau, off South Carolina, Georgia, and northern Florida. And one can anticipate that the U.S. government will move quickly to complete the kind of legal-regulatory regime that will encourage aggressive evaluation of any deep-sea polymetallic sulfide deposits within 200 nautical miles of our shoreline.

With regard to sulfide and nodule deposits beyond national resource jurisdiction, the outlook is much more complex. The entry into force of the LOS Treaty will not occur until 60 countries ratify it, a process that in the past has taken six years or more. Although Third World nations could readily muster the necessary 60 ratifications from their number, they may be reluctant to do so until they see how many and which industrialized nations also ratify it. And ratification by many industrialized nations may await the development of proposed implementing rules and regulations by the Preparatory Commission, which will begin work when 50 nations have signed the Treaty, possibly by the spring or summer of 1983.

In one of its final actions at the New York session this spring, the LOS Conference dealt with the need of the existing seabed mining industry for some sort of legal protection for investments made prior to entry into force of the Treaty. Complex provisions were adopted which, in effect, guarantee that "pioneer investors" who have made investments exceeding a certain level by January 1, 1983, can apply to the Preparatory Commission for an exploration authorization for one of two equally valuable mine sites (the other would have to be set aside for the future Enterprise). When the Convention enters into force, each pioneer investor would be authorized to begin commercial production under the limitations brought into play by the overall production ceiling, provided he is found in compliance with the other strictures of the Convention.

In the coming months, the spotlight is going to be on Britain, West Germany, Belgium, and Italy. All four of these industrial nations have seabed mining interests, and all four *abstained* in the April 30 vote to adopt the LOS Convention.

In effect, each of these nations has three options with regard to the legal-regulatory regime for seabed mining:

1) Decide to sign the LOS Convention later this year, obtaining the right to participate in the work of the Preparatory Commission as it formulates seabed mining rules and regulations and thereby also obtaining eligibility for its mining companies to be designated as pioneer investors.

2) Decide not to sign the LOS Convention, presumably preferring to work on a legal-regulatory approach under national legislation.

3) Decide to defer a decision on signature in order to assess the outcome of the Preparatory Commission.

If these nations choose to sign the Treaty, they will then be constrained under international law to ensure that their participation in any other agreement does not defeat the purpose of the Treaty. Under such circumstances, arrangements under national legislation would be even more clearly designed as interim and preparatory for the Treaty's legal-regulatory framework. In this scenario, the U.S. would have difficulty interpreting the national legislation approach in such a way that it, by itself, provides the legal framework needed by its seabed mining industry. U.S. companies also would have difficulties acting alone because all of them are members of consortia with foreign partners.

If, on the other hand, other industrialized seabed mining nations do not sign the Treaty, and instead join the U.S. in pursuing an alternative legal-regulatory regime with interlocking national laws backed by a different interpretation of international law, then the situation might be different. Conceivably, such an approach could provide a measure of mine site security. However, the fact that France and Japan, both seabed mining nations, voted for the LOS Treaty and presumably will sign it as well, would appear to circumscribe this alternative.

By the spring of 1983, the situation could be clearer. By then some or all of the abstaining nations will probably have decided whether or not to sign the Treaty. If all decide to sign and thereby participate in the work of the Preparatory Commission (including the granting of "grandfather" rights to pioneer operators), a "ripening" legal-regulatory framework will be in place. This framework, in theory at least, will begin to create the legal rights and guarantees needed for the seabed mining industry to develop further. However, significant amounts of private investment probably will flow to this new industry only when the long-term outlook for metal prices brightens. Furthermore, the complexities, political and otherwise, built into the LOS provisions governing seabed mining may prompt the free market oriented private sector to shun this "opportunity," even with the prospect of attractive metal prices. This would leave further development and commercialization of seabed mining to the largely state-owned or state-funded companies of nations like France, Japan, and the Soviet Union, and to The Enterprise.

Should some seabed mining nations sign the Convention and others postpone their decisions, the result would be a continuation of the present uncertain situation, delaying still further the time when seabed mining could become a commercial reality. Unfortunately, this is probably the most likely prospect.

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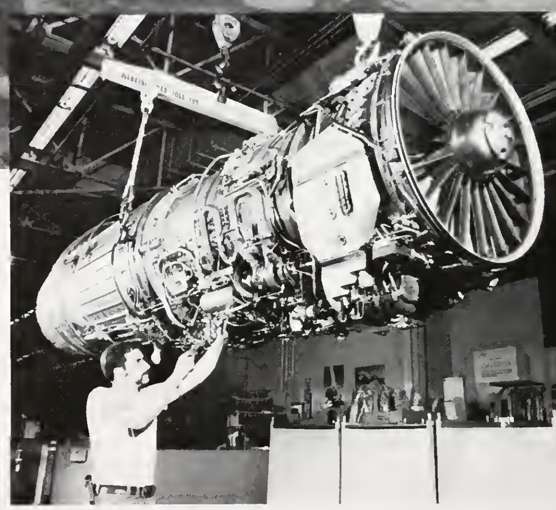
SCOR Comments on Seabed Mining

The Scientific Committee on Oceanic Research (SCOR) and the Advisory Committee on Marine Resources Research (ACMRR) of the Intergovernmental Oceanographic Commission (IOC) have just produced a report on "Future Ocean Research" that includes a section on "Underwater Minerals and Mining." The study, chaired by Eugene Seifold with Warren Wooster serving as rapporteur, calls for more investigation of the variations in manganese nodule abundance. "The need is to develop predictive methods that can help to locate areas of potential value both quickly and cheaply."

The report also speculated that "it is in island arcs and oceanic fracture zones that the best developed and most economically valuable hydrothermal sulfide deposits may be found. Both of these features contain deep basins in which metalliferous muds could be ponded leading to the formation of larger deposits than have been found to date on mid-ocean ridge crests" (see page 42).



More than 900 pounds of cobalt are needed to produce the engine (inset) for this U.S. Air Force F-16 fighter plane. (Photos courtesy of Pratt & Whitney Aircraft Group — United Technologies)

The Argument:

The U.S. Will Need Seabed Minerals

by William P. Pendley

In 1970, a forward-looking 91st Congress, concerned with long-term surety of national mineral supplies, adopted the Mining and Minerals Policy Act, calling upon the Executive Branch to "foster and encourage" the domestic minerals industry. For 11 years, little was accomplished in furtherance of that Congressional directive.

In September 1980, Governor Ronald Reagan became the first presidential candidate in history to recognize not only the critical link that minerals have to the national defense, but their imperative relationship to economic recovery. Shortly after his inauguration, the President's concern for strategic and critical minerals as part of defense preparedness was further demonstrated by his announcement of the first major purchase for the National Defense Stockpile in more than 20 years. His Cabinet Council on Natural Resources and the Environment established the Strategic Materials Working Group to prepare a major presidential statement on minerals and materials policy, a statement that was signed and issued by the President on April 5, 1982 — the first

such policy pronouncement since 1954 and, I believe, the strongest statement on minerals policy ever issued by a president.

With the inauguration of President Reagan and the swearing in of his Cabinet, this minerals issue, ignored for decades, became a matter of concern for not just one or two officials but for the entire Administration:

President Reagan: "It is the policy of this Administration to decrease America's minerals vulnerability . . ."

Secretary of Defense Weinberger: "The Soviets are also seeking to develop a viable oil and strategic minerals denial strategy . . . to erode both the economic health and political cohesion of the West."

Secretary of the Interior Watt: "We face a hidden crisis caused by past failures to provide for a domestic supply of strategic minerals for defense and industry."

Secretary of Commerce Baldridge: "Our policy recognizes minerals as an important part of both the American economy and the national security . . ."

It was this larger view of America's strategic mineral interests that spurred the difficult decision to undertake a fundamental re-examination of the Law of the Sea Draft Convention and the interests of the United States regarding that convention. On March 2, 1981, one week before the beginning of the Tenth Session of the Law of the Sea Treaty negotiations, the United States announced its decision to undertake the review. The review process was doubly difficult because it was undertaken so late in the negotiations and because it had to reassess prior concessions made in the name of the United States. Yet it was a critical review given the changes in world relations since sea treaty discussions began more than a decade ago. In late April, 1982, at the end of the eleventh and final session, the U.S. was one of four nations to vote against the treaty because, in the words of President Reagan, "the deep seabed mining part of the Convention does not meet United States objectives."

It is seldom possible to identify the end of one era and the beginning of another during the time when the events of change are under way. However, the Law of the Sea Convention may someday be viewed as a turning point — where the United States began seeing the world from a nationalist perspective. If so, the Law of the Sea Treaty could be seen as a process begun in one era and rejected in another.

In the 14 years since the beginning Law of the Sea discussions, America had changed its perception of long-term mineral interests and of the implications of technological improvement in the field of deep seabed mining. Now, at a time less than a decade after the Arab oil embargo led to a consensus on U.S. national security interests in foreign energy supplies, at a time four years following the disruption in Zaire's Shaba province and its consequences on world cobalt prices, at a time of justifiable concern over a growing resource nationalism in evidence among suppliers of strategic and critical minerals, long-term mineral adequacy must become a national issue. It cannot be put off until supplier actions, of whatever kind, threaten availability. As well, seabed mining concepts that stretched the imagination in 1970 are closer to reality now — projects that appeared impossible by their scale a decade ago are restrained now primarily by economic and legal parameters, not by technological limitations.

Technological Advances

We have only to look at the phenomenal accomplishments in oil and gas exploration and production on the Outer Continental Shelf to see what private initiative can do to overcome tremendous physical obstacles when there is a commensurate return on investment. The responsiveness of technology to the demands of the marketplace is evident from the development of offshore drilling platforms. Some early wells were developed from piers. In 1947, the first well was drilled out of sight of land, in 6 meters (20 feet) of water. Even in 1957–58, when the Convention on the Continental Shelf was being discussed at the First United Nations Conference on the Law of the Sea, the deepest waters considered significant for oil and gas development were 200 meters or less.

Figure 1 illustrates the development of one class of offshore platform. It is important to note that at each stage reservations were expressed regarding the limits of the technology. However, such reservations were addressed, the technological hurdles overcome, and progress made, utilizing basic concepts that had been discussed many years previously. Each age marvels at the limits the previous age placed upon its technology. We find ourselves limited only by the past, not by the future.

Prospective seabed mining activities encompass not only the collection of manganese nodules (with their significant content of cobalt, copper, manganese, and nickel) but also the

The Shaba Disruptions

Because of the high cobalt content of the copper ore in its province of Shaba, the African country of Zaire is able to supply more than half of the world demand for cobalt. The importance of cobalt to the high-tech nations of the world was demonstrated in 1977 and again in 1978, when insurgents from the Baluba and Balunda tribes crossed the border from Angola and Zambia to occupy some Shaba mines. They sought the overthrow of Zaire's President Joseph Mobutu. Before the first incursion, the Soviet Union had purchased large quantities of cobalt, reducing the supply of the metal even before mining was interrupted. Both incursions were driven back by French and Moroccan troops. The conflict, however, scared away many Belgian mining technicians. Zaire's economy, heavily dependent on mining, was in general disarray. The price of cobalt soared.

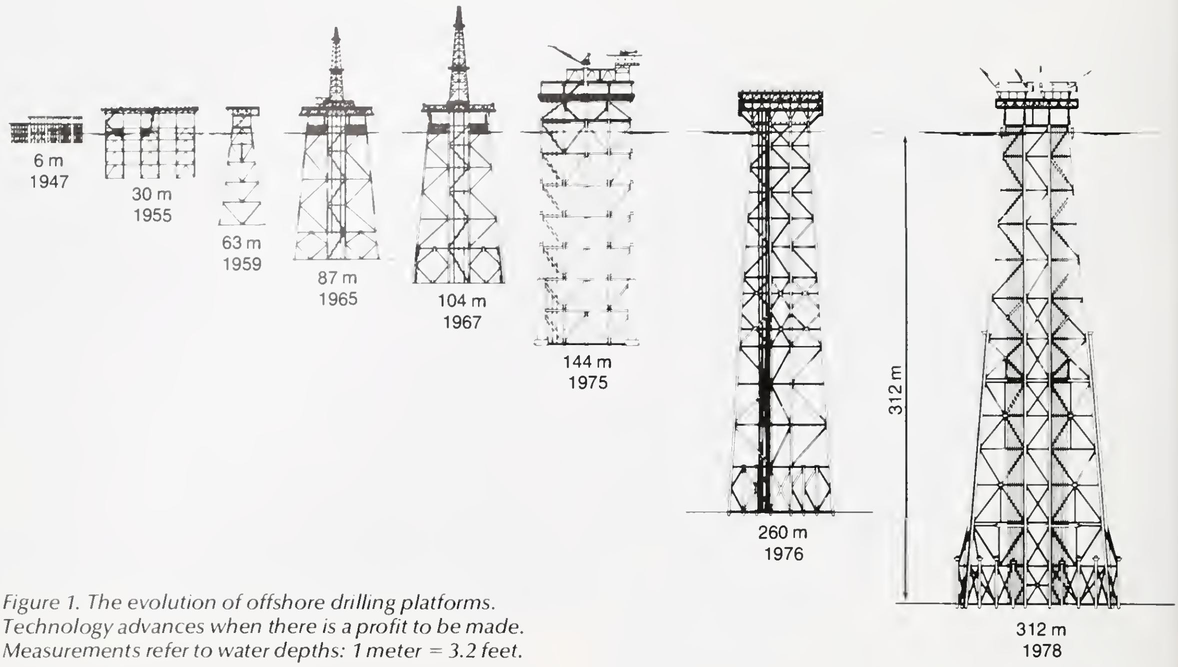


Figure 1. The evolution of offshore drilling platforms. Technology advances when there is a profit to be made. Measurements refer to water depths: 1 meter = 3.2 feet.

exploitation of recently discovered massive metallic sulfide deposits in the Pacific Ocean (see page 42), hydrocarbons beyond the 200-mile limit, and other deposits yet to be discovered. As recently as five years ago, the sulfide deposits of the spreading centers — subject of such recent excitement (see *Oceanus*, Vol. 25, No. 2, p. 22) — were suspected only as scientific possibilities. We can forecast neither sea-floor discoveries nor the technology that will eventually lead to development of those resources.

The history of mining is the history of technological advances that produce not merely the ability to detect and evaluate previously unknown mineral resources, but the skill to convert those resources into commercially developable reserves — ore from rock. Only through nondiscriminatory access and secure tenure, a marketplace that fosters the development of required technology, and an economic system that encourages private risk-taking, can America feel comfortable about a future that demands minerals for national defense, for economic growth, and for maintaining our standard of living.

The essence of minerals policy is having the broadest possible base of minerals available in the quantities needed to meet the needs of the domestic economy, to ensure, to the extent possible, that those supplies are not vulnerable to disruption by the actions of foreign producers, and, where vulnerable, to have sufficient flexibility to assure responsiveness of supply. A technologically advanced nation, responsible for its own defense as well as the defense of others, must have assured sources of supply for both fuel and nonfuel minerals. Of course, the development of those sources, to the extent possible, must minimize adverse environmental impacts while ensuring the most efficient usage of the nation's limited capital resources.

America — once a nation of farmers — is quick to appreciate and understand the threat posed by a loss of agricultural self-sufficiency. What we have failed to adequately address and understand in the past is the threat to national security posed by our lack of self-sufficiency in the case of an equally important natural resource — minerals.

Simplistic Theories

Too often in the 1970s, theorists, quick with answers to mineral supply problems, posed as ready solutions the famous trio of recycling, substitution, and conservation, backed up by their second cousin — diversification of supply. What was not understood by such theorists was that the trio does not offer an efficient response to shortages from primary sources of supply. Recycling, substitution, and conservation involve real, calculable costs — inefficiency and economic dislocation.

If we have learned anything, it is that the market system, operating as it should, is the motivator of technologic developments that constantly improve the efficiency of use of metals and minerals in their hundreds of thousands of applications. It is the market system that spurs substitution in the technologic sense of striving for a more efficient use of materials that produce better products or increase the productivity of our machines. Substitution should not be accepted as a simplistic solution to supply problems. What makes the trio of alternatives acceptable is the unavailability or shortage of the preferred source of supply — such as wartime dislocation — or a conscious decision not to develop that preferred

source in the face of higher national priorities. If there is merit in declaring any particular source of supply off limits, then that must be the justification — not the fact that government by fiat or regulation can compel less consumption or more costly use of alternative materials.

Diversification of supply as a solution to shortages was an answer that seemed ever so reasonable to those who simply had to write the words. Little was said, however, of where the alternative sources might be discovered, or who would share the risks of development. This magic wand assumed that the private sector could assume the risk of exploration, mining, and processing, which, along with the necessary infrastructure, might cost more than a billion dollars. While economic theorists can respond to the threat of mineral shortages with a call for diversification (the use of minerals from as yet undeveloped sources of supply), it is the private sector — specifically, the person with fiduciary responsibility to stockholders — that must make diversification a reality. Is it any wonder that mineral experts scoff at these "solutions" to mineral shortages and are repelled by the assertion of some who, despite obvious excitement on the part of the business community, claim that we do not need deep seabed mining?

More than a decade ago, the Public Land Law Review Commission, responding to a Congressional mandate, found mineral development on public lands to be the highest economic use of those lands, given the value of the mineral deposits and the rarity of their occurrence. The concept applies equally offshore. A resource adds wealth only with its use, and the essence of conservation should direct that resources not be denied to a nation or a world without a conscious decision to do so. We cannot declare the sea and its resources off limits in the face of such serious need by this country, its allies, and the rest of the world.

Import Dependency

Today the United States is dependent on foreign sources for a significant portion of its strategic and critical minerals, including substantial portions of those potentially available from manganese nodules on the seabed. Cobalt is not mined domestically, with more than 90 percent of our supply — 100 percent excluding recycled (secondary) supplies — coming from foreign sources, primarily southern Africa. Nickel is mined in America, but more than 70 percent of our stock is imported, mostly from Canada. The United States is almost self-sufficient in copper, but is essentially 100 percent dependent on foreign sources for manganese, with most of that supply originating in central and southern Africa.

The mining of deep seabed mineral resources could contribute substantially to our domestic supply of these minerals, providing in the process new jobs, new tax revenues, and the direct and indirect benefits that come from investments in technology. While few claim that such mining would result in self-sufficiency in any of the nodule minerals, it would provide a safer mix of sources.

Since the Organization of Petroleum Exporting Countries (OPEC) actions on petroleum prices of the last decade, there has been discussion of the need of the United States to be aware of political or military actions that could disrupt foreign supplies and of the possibilities for mutual pricing arrangements between major suppliers. In the context of seabed mining, these concerns have focused on three metals (as the United States is a major copper producer): nickel, cobalt, and manganese. An added concern is the possibility that the Soviet Union could engage in a "resource war" by disrupting world markets and limiting the availability of these materials. Cobalt is of particular concern.

The dominant role of African nations in supplying cobalt to the United States is revealed by an examination of the supply-demand chart of Figure 2, and the simplified chart of Figure 3. Zaire accounts for about 59 percent of U.S. cobalt imports (directly and through Belgium). Combined with Zambia, Botswana, and South Africa, approximately 80 percent of U.S. cobalt came from central and southern Africa in 1978. Aside from seabed minerals, southern Africa accounts for 66 percent of the world's known cobalt reserves. Table 1 shows world mine production of cobalt for 1978, figures which have remained relatively stable since that time. Zaire's 29.3 million pounds was approximately 52.5 percent of the total. Figure 4 illustrates the

Table 1. World cobalt mine production, 1978, and capacity 1978, 1979, and 1985
(Thousand pounds)

	Production	Capacity		
	in 1978*	1978	1979	1985
North America:				
Canada	2,720	3,600	3,600	5,000
Cuba	3,600	3,600	3,600	4,000
Total	6,320	7,200	7,200	9,000
Europe:				
Finland	2,858	2,900	3,000	3,500
U.S.S.R.	4,300	4,400	4,400	4,500
Total	7,158	7,300	7,400	8,000
Africa:				
Botswana	576	600	600	1,000
Morocco	2,500	2,500	2,500	2,500
South Africa	200	200	200	500
Zaire	29,320	35,000	35,000	42,000
Zambia	3,822	4,000	6,000	12,000
Total	36,418	42,300	44,300	58,000
Oceania:				
Australia	3,000	3,000	3,500	4,000
New Caledonia	340	500	500	2,000
Philippines	2,626	2,800	2,800	3,000
Total	5,966	6,300	6,800	9,000
World total**	55,862	63,100	65,700	84,000

*Estimated recovered cobalt content.
**Data may not add to total shown because of independent rounding.

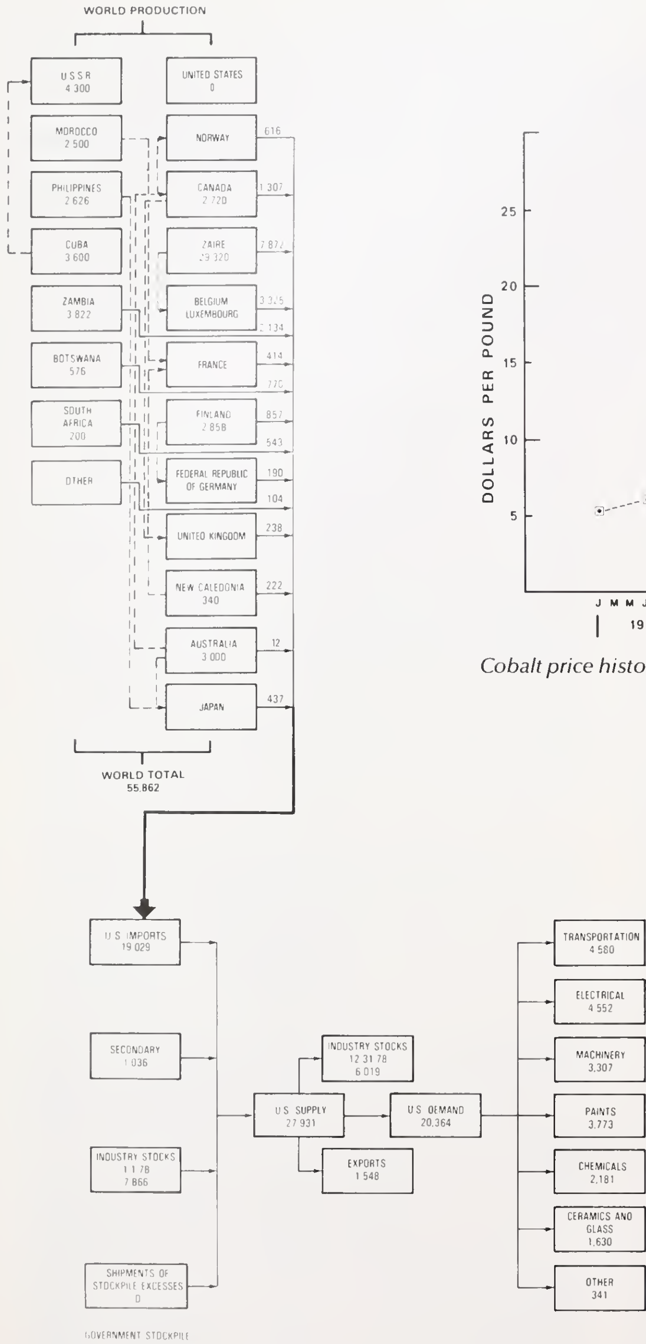
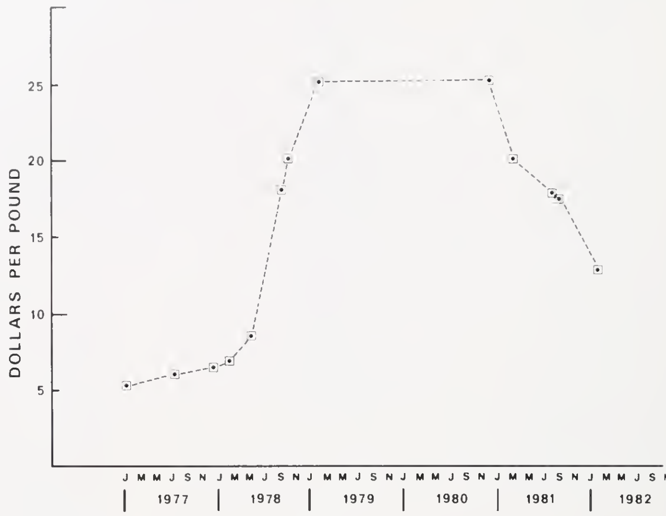


Figure 2. This chart shows the supply-demand relationships for cobalt in 1978, in thousands of pounds. Dashed lines indicate raw ore sent to another country for processing. Some nations, such as Zaire, export both raw and processed ore. "Secondary" refers to cobalt obtained by reclaiming scrap and industrial wastes. (Source: Bureau of Mines, U.S. Department of the Interior)



Cobalt price history from 1977 to early 1982.

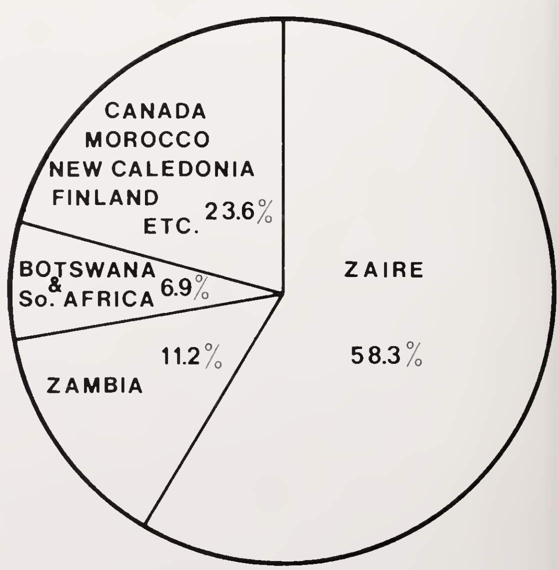


Figure 3. Mine production sources for cobalt imported by the United States in 1978.

DISTRIBUTION OF ESTIMATED WORLD REFINED COBALT METAL AND CHEMICAL COMPOUND PRODUCTION IN 1979

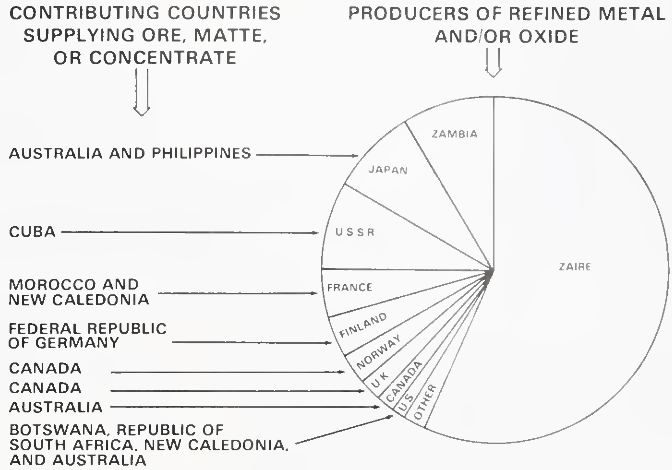


Figure 4. Zaire, Zambia, the Soviet Union, Finland, and Canada mine cobalt as well as refine it. (Source: Bureau of Mines, U.S. Department of the Interior)

production of refined cobalt and chemical compounds, again showing the significant role of Zaire. Zaire's dominant pricing influence in the world markets began with supply curtailment stemming from the 1978 Shaba disruption. That price influence was exercised in close consort with Zambia over the next several years. Only recently, as a result of economic slowdown among its major industrial consumers, has that strength yielded to price concessions.

Cobalt as a by-product of copper and nickel mining possesses little elasticity in supply. While the jump in the price of cobalt caused a number of copper and nickel producers to improve the recovery of cobalt from their ores, that effort was unsuccessful in dislodging Zaire from its key position. Thus the United States and other major consumers will continue to be heavily dependent upon a relatively small region in southern Africa for their vital supplies of cobalt. If we intend to maintain an edge in jet engine technology and to improve our capability to drill deeper oil and gas wells, we must keep our options open for new cobalt supply sources whether they be found in Missouri, Idaho, California, or at some point midway between the West Coast and Hawaii.

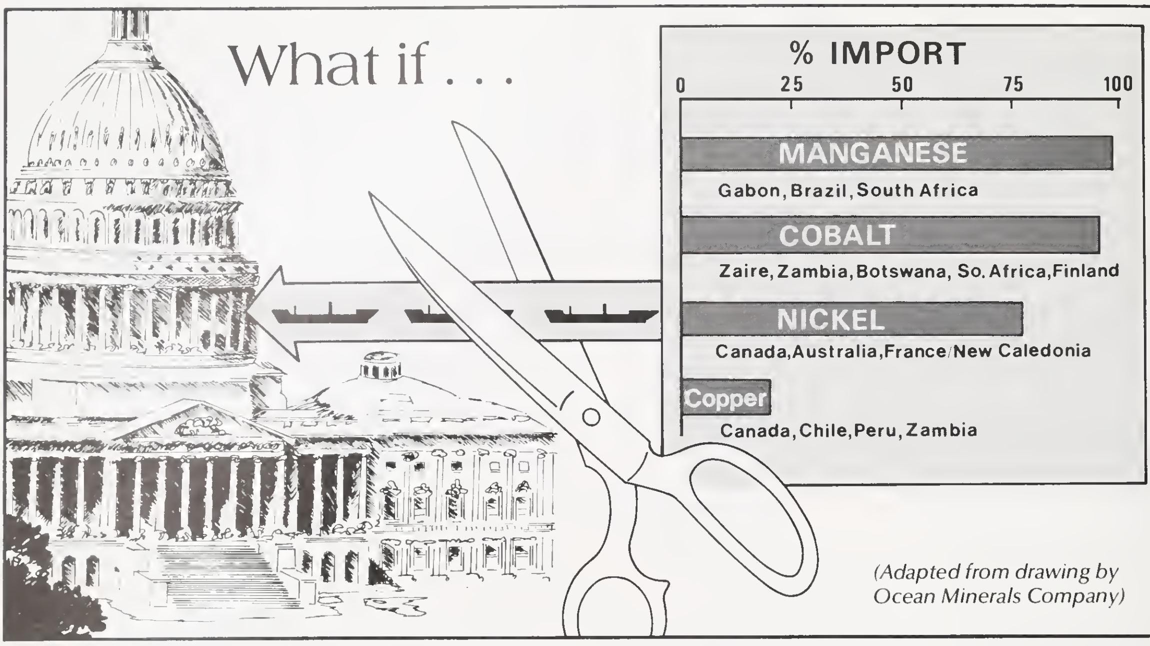
Strategic Needs

There is little question today regarding the strategic nature of the minerals known to occur on or below the deep seabed. Their importance to the national defense, to essential civilian industrial uses in times of war, and to sustaining economic growth has been well established: cobalt adds temperature- and wear-resistance and high strength to an array of superalloys and specialty steels so vital in jet engine parts, cutting tools, and hard-facing applications; manganese is so fundamental in the production of virtually all steels and most cast irons that major technical and economic upheavals would result from a cutoff or a substantive constraint in supply; and nickel, in its major alloying role, is exceeded in tonnage use only by manganese and chromium.

While stockpiled materials provide a measure of protection in times of national emergency, many stockpiles are far smaller than they would have to be to see the country through the first three years of a major conventional war. In addition, only the United States among the western developed countries has established defense stockpiles despite an even greater dependence by many of those countries on offshore supplies. In the face of potential exigencies, it makes little sense to rule out any potential resources — be it manganese nodules or resources yet undiscovered. While government policymakers or academic theorists can argue regarding the relative merits of various resource development proposals or the likelihood of their success, the decision must be made by the free market system. Technological advances must be allowed to develop if we are to obtain minerals economically.

What is not subject to dispute is the critical need of the United States and its allies for such raw materials as cobalt, chromium, manganese, platinum, and nickel. We cannot afford, as a nation and as the leader of important alliances, to prejudge the viability of any given mineral resource, to decide as a government that potential shortfalls would not be serious, that stockpiling meets all our security needs, that substitution, recycling, and conservation will make up the difference, and that America therefore can do very well without seabed minerals. To take such an approach would be to deny America a vital resource that could well become critical to our strength.

William P. Pendley is Deputy Assistant Secretary for Energy and Minerals, U.S. Department of the Interior. (The opinions expressed in the article are those of the author and not necessarily the policies of the U.S. Government or the Department of the Interior.)



(Adapted from drawing by Ocean Minerals Company)

The Rebuttal:

The Nodules Are Not Essential

by Joel P. Clark

Manganese nodules, which contain significant quantities of cobalt, copper, manganese, and nickel, are considered by the Reagan Administration, and others, to be an important future source of minerals that are crucial to U.S. industrial and national security interests. Although it is clear that there would be some economic benefits — principally lower market prices, less likelihood of supply disruptions, and reduced probability of cartelization — if the nodules were mined by the U.S. on a unilateral basis, it is not at all clear that mining in this fashion would be crucial to national security. Moreover, there are important international political implications associated with unilateral action, and it is the belief of this author, based on the best available data, that the United States would be better served to pursue a policy course on mining within the framework of the recently adopted Law of the Sea Convention.

The Consequences of Not Mining Nodules

The central issue in the debate concerning whether or not it is essential to mine deep-sea nodules in the near future revolves around the potential consequences of not having the nodules as an additional source of supply. Let us consider a scenario in which deep-sea nodules are not mined and the worst-case supply disruptions occur in the markets for copper, nickel, manganese, and cobalt. In the event of such disruptions, what would happen to supply, demand, and prices, and what would be the consequences to the U.S. economy and national security?

Copper

The net effects of not having an additional source of copper from deep-sea nodules are nil. Although there is in theory a copper cartel (CIPEC, consisting of Chile, Peru, Zaire, and Zambia), members of this group have been totally unsuccessful in controlling supplies and prices, principally because a) major producers, such as the United States, Canada, Australia, and Papua-New Guinea, are not members; b) the CIPEC group members control only 30 percent of world copper

production; and c) secondary copper and substitute materials offer viable alternatives to copper, therefore limiting the market power of an oligopoly (just a few sellers) by establishing limits on the price.

In the unlikely event that the CIPEC cartel were able to exert market power, domestic consumers of copper would still be relatively unaffected since the United States currently produces 80 to 90 percent of domestic consumption and, if necessary, could become self-sufficient in copper. Moreover, the amount of copper that can be expected to accrue from deep-sea nodule mining is so small (about 1 percent of world supply) that it would not affect the markets in this country or internationally.

Nickel

The probability of a supply disruption in the nickel market is also small. Nickel supplies are relatively diverse, and the most important producing countries — Canada, Australia, France/New Caledonia — are generally friendly to the United States. Although the North American nickel industry has been dominated by a single company, INCO, that company has been gradually losing market power. In Canada, INCO shares the market with several other nickel producers and its market share is now below 50 percent. Moreover, the early to mid-1970s witnessed the opening of new nickel mines, particularly in Southeast Asia and Australia, resulting in appreciable oversupply and competition within the industry for North American and world markets.

The contribution to nickel supplies expected from manganese nodule mining would not greatly affect the competitive situation of the industry. Although such mining would affect nickel supplies and prices, a 3-million-metric-tons a year operation would produce somewhat less than 5 percent of the nickel consumed in 1980. Four ocean mining operations starting in 1990 would lower the nickel price about 7 percent, and two more operations initiated in 1995 could lower the price by an additional 2 percent. In any case, deep-sea nodules would not deter nickel supply disruptions and would not be a significant alternative source of nickel in the event of a disruption.

Manganese

The probability of supply disruptions in the manganese market is lower than for cobalt, but is not negligible. In 1980, about 75 percent of the nation's manganese ore requirements were imported from Brazil and Gabon, with much of the remainder coming from South Africa. While the preponderance of world reserves is located in South Africa and the Soviet Union, manganese is also mined in Australia and India.

The effects of a supply disruption on the market for manganese, however, may not be relevant to the debate surrounding deep-sea mining. Only one consortium — Ocean Mining Associates — has announced plans to proceed with manganese recovery processing technology, because the profitability of recovering manganese from nodules is questionable. Nevertheless, it is important to note that there are manganese substitution and conservation options available to American consumers if manganese prices escalate in the future. It is estimated that if the price of manganese ore doubles, consumption of manganese by the carbon steel industry in the United States would decline by 10 percent in one year and by 24 percent at the end of five years. Similarly, a 10-fold increase in the price of ore would result in a 15-percent decrease in consumption in the first year and a decline of almost 50 percent by the end of seven years.

Cobalt

Financially and strategically, cobalt is the most important material contained in deep-sea nodules. Although the cobalt contained in nodules is only about 0.25 percent, the price of cobalt is relatively high. Indeed, the future cobalt price is one of the most critical uncertain factors in determining the profitability of deep-sea nodule mining.

Cobalt is considered by many to be both a strategic and a critical material for the United States; strategic, because of its use as a high-temperature material in jet engines and industrial gas turbines and as a catalyst for petroleum desulfurization; critical, because the United States imports virtually all of its supply of primary cobalt and a large percentage of these imports comes from countries with potentially unstable political environments (Zaire and Zambia for example). Before analyzing the effects of supply disruptions on the cobalt market, it is useful to consider briefly what is meant by the terms "requirements" and "demand" for materials.

The term "demand" refers to that quantity of consumption which exists at varying levels of price, other factors being constant. One usually expects the demand for a material to be inversely correlated with its price and directly proportional to the level of economic activity in the industrial sectors that use the material. If prices rise, one expects demand to decrease if economic activity and other factors remain unchanged. "Requirements" refer to the level of consumption of a material by domestic consumers that is expected to occur based on technological and market growth assumptions. The concept of "requirements" thus implicitly assumes that the price elasticity of demand is small enough to be neglected.

Much of the debate concerning the criticality of cobalt and other materials has focused on projections of the requirements for these materials and not on an analysis of demand. However, it is the demand analysis that is most useful for evaluating future materials consumption. The appropriate question is: if prices rise (for example, because of a supply disruption), what will the demand be for these materials this year, and in the future? The recent experience regarding the effects of price changes on the consumption of cobalt in the United States provides a dramatic illustration of the possibilities for substitution by other materials, and the resultant elasticity of demand.

The substitution effects can be more easily understood by considering the end-use markets separately. The three most important uses of cobalt on a tonnage basis in the United States are in

superalloys, as an alloying element in permanent magnets, and as an element in chemical compounds. Other important uses include cemented carbides, hard-facing and welding materials, and as an alloying element in steels. Several factors influence the substitution dynamics: 1) the fraction of the end-use sector that is technically substitutable (at any price); 2) the fraction of the sector that is economically substitutable (at various levels of price); and 3) the time required for the substitution to proceed once it has become feasible to switch.

The world cobalt market was recently studied by Charles River Associates (CRA) for a group of industrial clients. It was found that there is considerable price elasticity in the demand for cobalt, because, as the price rises, consumers shift their preferences to alternative materials and designs. Furthermore, the increase in price encourages conservation of cobalt through increased recycling and improvements in processing techniques. For instance, the study showed that if the price of cobalt were to stabilize at $25 a pound (in 1978 dollars), the demand for cobalt would decline to less than half of its initial value within five years. The short-term response would be less, but there would still be a decrease of approximately 15 percent in the total demand for cobalt within one year if the price were to increase from $10 to $25 a pound. The results of the substitution analysis, which was developed in 1978, have suffered the test of time well, and were used as part of an overall supply-demand framework to predict quite accurately the time path of world cobalt prices over the period 1978-82.

The results of the substitution analysis are crucial to an understanding of the economic and national security consequences to the United States of a supply disruption in the world cobalt market. It is entirely conceivable, even likely, that another supply disruption will occur because of the political instability in southern and central Africa. If such an event occurs, it is clear that the price of cobalt will again rise as the result of psychological factors and actual production curtailments. The magnitude of the price increase is uncertain, but it is quite unlikely to increase above $50 a pound for any appreciable period because of the downward pressure from substitution and additional supplies from other nations. The results of the analysis may be interpreted as follows:

If the price were to increase by a factor of 2.5, and other parameters (such as industrial activity and prices of substitutes) were to remain unchanged, the total demand for cobalt in the United States would decrease by 15 percent in a one-year period. A price increase by a factor of five would bring a demand decrease of 20 percent in the first year. Currently, about 15 percent of cobalt supplies in the United States come from recycled (secondary) sources. Thus even if supplies were restricted by 50 percent, in the first year of the disruption only up to 20 percent of demand would have to be met by releases from the government stockpile. Of course, the greater the price, the less the demand and the greater the contribution from recycled material.

If the supply restriction were to last for more than a year, demand would have more time to adjust and there would be more substitution. Thus the overall demand for cobalt in the United States would decrease by 50 percent in years two through seven, with a price increase factor of 2.5, if other factors were to remain unchanged. In the event of larger price increases, substitution would be greater. If the disruption were to continue, there would also be time for additional sources of supply to respond to the higher price.

Indeed, we have seen such responses by both the demand and supply sides of the market to the 1978 disruption. Following the disruption, the producer price was set at $25 a pound and an attempt was made to maintain the price at that level. However, because of substitution and increased supply from other sources outside Zaire and Zambia, large stocks were built up by producers, and the free market price has declined to less than $10 a pound in 1982. Consequently, extreme pressure has been placed on the producer price, and it too has been gradually decreased to the point where it is now about $12 a pound.

CRA, in examining the potential effects on the United States economy of mineral supply disruptions, developed an "optimal stockpile model" to estimate the cost of such disruptions. The expected present value of the cost of a disruption in the market for manganese was calculated to be about $2.5 billion (in 1978 dollars). The cost of the recent cobalt crisis in Zaire was about $900 million (1978 to 1980). The optimal stockpiles implied by the CRA study are enough manganese for 12 to 18 months (worth approximately $200 million at current prices), enough cobalt for about 12 months (worth $270 million at a price of $15 a pound), and enough copper for one month (worth about $500 to 700 million at a price of $1 a pound). The actual strategic stockpiles of cobalt and manganese already held by the U.S. Government are considerably larger than these figures.

It can be argued that supplies of manganese and cobalt from deep-sea nodules could reduce the expected cost of a disruption and might eliminate the need for substantial stockpiles. If so, the potential economic benefit to the United States would be somewhere between $500 million (the cost of economic stockpiles that may not be necessary) and $4 billion (an estimate of the discounted cost of possible future supply disruptions of manganese and cobalt, weighted by the probabilities of their disruption). These figures are uncertain because estimates are required of factors such as interest rates, prices, and probabilities of disruption. However, they do indicate the approximate range of economic benefits that could result from deep-sea mining.

Two major conclusions may be drawn from this analysis:

- *A disruption in cobalt supplies from Zambia and/or Zaire would not have a measurable effect on the national security of the United States. The increased prices would result in substantial substitution away from cobalt in "non-essential" uses. However, there would be a time delay, and it might be necessary to release a small amount*

of cobalt from the government stockpile for one or possibly two years.

- *There would be an economic cost to the United States resulting from a supply disruption because of the loss in consumer surplus. The costs of such a disruption could be substantial but would be short-lived because of the downward pressure on the price.*

The Political Implications

The adverse political consequences of mining the nodules concern the implications of unilateral action by the United States. In a speech before the United Nations General Assembly in 1967, Arvid Pardo, the U.N. ambassador from Malta, first suggested that the resources of the deep seafloor were the "common heritage of mankind." Although the U.N. has officially accepted this new status for deep seabed resources, the legal implications will be ambiguous and impotent until they are precisely defined in a fully ratified Law of the Sea Treaty.

The great fear of the developing world is that industrialized countries will gain control of the markets for the metals contained in deep-sea nodules. Moreover, it is clear that deep-sea mining, when it becomes economically feasible, will greatly reduce the mineral revenues of some developing states. Assuming that ocean mining were to begin in 1988, it has been estimated, using computer models, that cumulative losses could reach $6 billion (in 1980 dollars) by 1995. There would be two obvious consequences of unilateral action by the United States. First, we would appear to be arrogant and selfish — particularly to the developing world — if we act alone in exploiting resources that have been labeled the "common heritage of mankind." Second, if the United States acts unilaterally, we could be viewed as the source of the economic problems of those countries in the developing world that stand to lose substantial revenues when the nodules are mined. Such a perception could actually have the effect of decreasing our security of supply if we create a state of ill will among the mineral-producing countries of the developing world.

Summing Up

Unfortunately, as is usually the case with mineral market projections, the best information available at this time is academic in nature; academic, because we have not experienced lengthy disruptions (that is, of one to three years duration) in non-fuel mineral markets and do not have the benefit of observing the effects of commercial deep-sea mining operations. Therefore, we must estimate the potential costs and benefits of mining and not mining the nodules with the most effective tools at our disposal. In the present case, much of the "academic" data related to the substitution for cobalt was derived from extensive interviews with industry sources and from engineering estimates by faculty of the Department of Materials Science and Engineering at Massachusetts Institute of Technology. Moreover, the data relevant to substitution, conservation, and recycling in the cobalt market are currently being reviewed by a committee of the National Materials Advisory Board (of the National Academy of Sciences/Engineering) for a report to be published next year.

A coal-mining machine with carbide-tipped cutter bits. Cobalt, in the form of an ultrafine powder, provides the cement for the tungsten carbide used in this and many other cutting tools. (Photo courtesy of Mining Congress Journal*)*

Based on available information, I believe the national security implications associated with not mining the nodules are minimal and do not warrant unilateral action — or the threat thereof — by the United States.

The economic benefit is also insufficient to make unilateral action by the United States an attractive proposition. However, the potential benefit of $2.5 to $6.5 billion (in 1978 dollars) a year, accruing over a 20-year period (if production were to start in 1990) is not negligible. The U.S. should work within the framework established by the U.N. Law of the Sea Convention to pursue this economic benefit.

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The Ocean Mining Industry:
A Benefit for Every Risk?

The Deepsea Miner II, a converted ore carrier, is used by Deepsea Ventures, Inc., service contractor for Ocean Mining Associates, to conduct tests of seabed mining equipment. (Photo courtesy of Deepsea Ventures, Inc.)

by J. K. Amsbaugh and Jan L. Van der Voort

In pursuit of the opportunities open to the ocean mining industry lie the benefits of concentrated research and the risks inherent in a pioneer economic venture. Benefits have evolved from the many different fields of research related to ocean mining, including marine science, ocean engineering, ocean law and policy, metals processing, and economics. Although great progress has been made, the unknowns also are great, giving rise to the many risks involved.

Exploration, Mining, and Processing

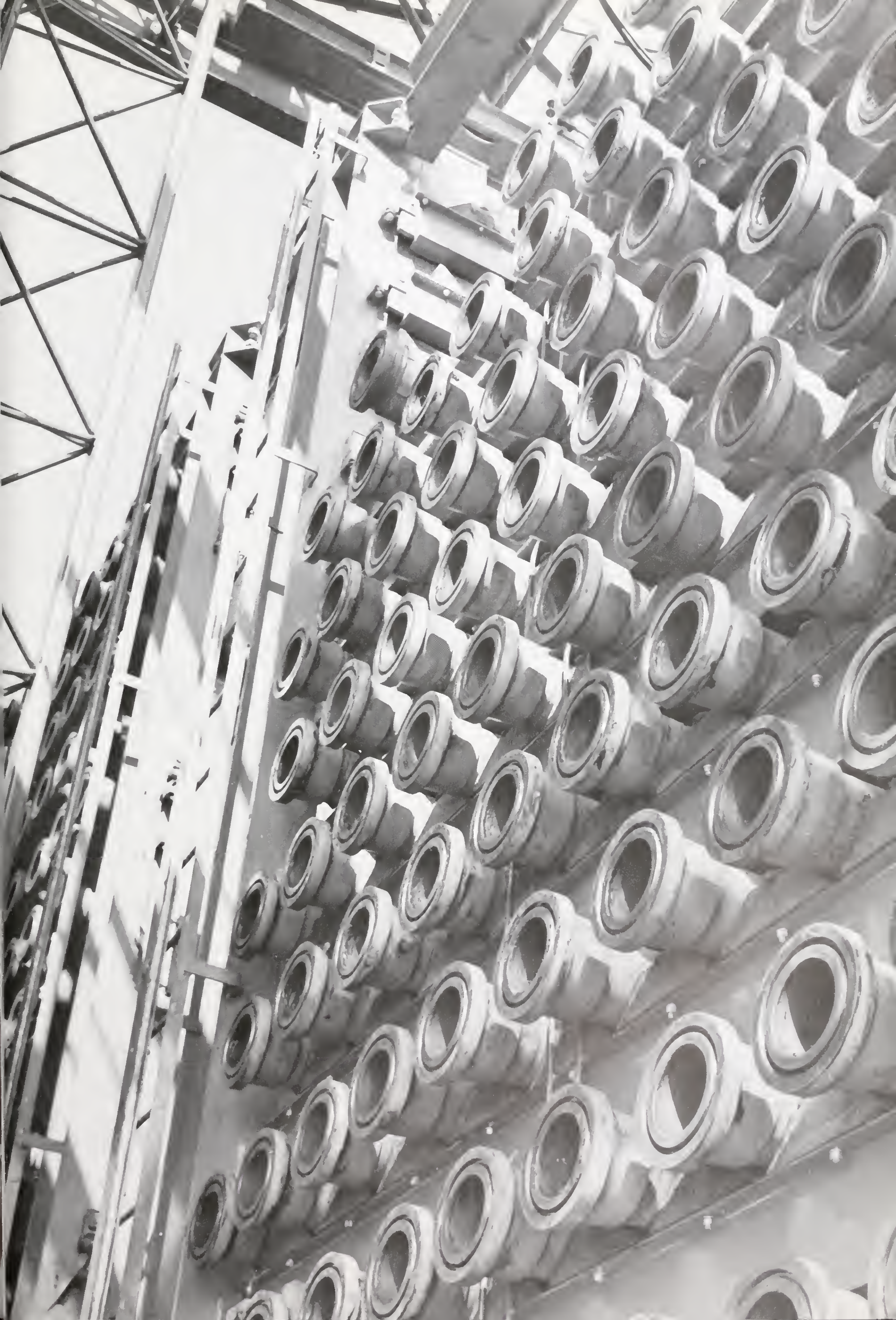
The area of ocean floor covered with manganese nodules is immense, the volume of metals there tremendous, but quantity alone does not an ore deposit make. The nodules are not uniform in size, metal content, or distribution. The potential mine sites are not smooth fields but areas interrupted by bumps, boulders, and cliffs. Beneath three miles of constantly moving water, sometimes violent at the surface, the pressure is four tons per square inch. The enormity of the challenge and the dimensions of the risks involved are unprecedented.

Unlike land-based mining and exploration enterprises, the ocean mining industry has little past experience to draw upon. The technology for finding, systematically collecting, and processing the nodules is still in an early stage of development despite the concentrated efforts of many large, high-technology companies during the past 14 years.

Identification of the topographical, textural, and chemical qualities of nodule resource areas is crucial to choosing a mining site. Mining equipment is designed for a particular range of nodule sizes, water depths, and specific bottom conditions. Some sampling and testing has already begun, and, with rights of access likely to be granted, the industry can now start a systematic program of exploration.

Extensive research has been undertaken to develop appropriate mining and processing systems. Research activities include engineering analysis and design, computer simulation, testing in the

At right, a pipe string in storage. The 460 sections are joined together to form a 15,000-foot pipe string, through which nodules travel from the collector to the surface ship. (Photo courtesy of Deepsea Ventures, Inc.)



laboratory, deep-ocean tests, and pilot plant operation. A great volume of information has been gathered and analyzed.

With ocean mining comes the potential for long-term scientific research, education, and the training of scientists and engineers. Once commercial systems become operational and profitable, mining ships and support vessels should be able to collect valuable oceanographic data for extended periods in the areas of operation. Exploration for other types of marine mineral deposits will be pursued both in the deep oceans and on the continental margins. The polymetallic sulfide deposits may be the next important target of commercial interest (see page 42). International industrial participants recognize their responsibility to share the benefits once the mining has begun. This means there will be opportunities for participation by oceanographers, contributions by industry to basic ocean research, and training in the fields of ocean engineering and marine mining.

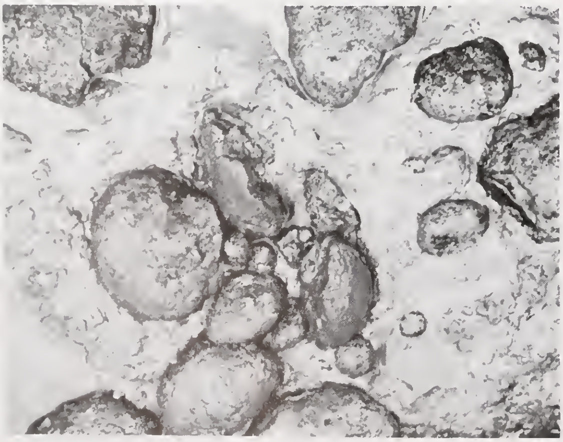
Market Uncertainties

In an effort to assure the availability of essential metals at reasonable prices, the world might look to the oceans to supplement land-based resources. Environmental constraints, geopolitical uncertainties, and the depletion of high-grade resources contribute to the concern over access to strategic metals. Deep seabed minerals are an abundant source of several strategic metals essential to both the continued growth of the developed countries and the anticipated industrial expansion of developing countries. Significant growth by the developing nations would increase worldwide demand for the metals.

The United States is almost entirely dependent on imports for manganese, nickel, and cobalt — metals essential for industrial maintenance and growth. Although the terrestrial resources of these metals appear to be sufficient for many years to come, access to them, from an economic and/or political viewpoint, is not guaranteed. Zambia and Zaire, countries troubled with unrest, supply most of the world's cobalt. The Soviet Union and South Africa are expected by some to control virtually all of the world's manganese resources by the end of the century. Much of the world's nickel resources are laterite deposits, the processing of which is very energy intensive. An independent, secure supply of these strategic resources would ensure against interruption of supply or high prices set by a cartel.

Behind the hopes for successful development of ocean mining resources lurks the uncertainty of the world marketplace. This uncertainty stems from two major factors: our inability to predict long-term demand and the possibility of political manipulation of supply. Before mining companies can accumulate the enormous amount of capital necessary for full-scale production, the markets for ocean mining products must be rendered predictable to a degree that is acceptable to financial officers and lending institutions.

One possible market for nodules and polymetallic sulfides is the U.S. government, which stockpiles critical metals for strategic safeguard and emergency needs.



A box-core sample of the Pacific Ocean floor allows direct observation of the relationship of manganese nodules to the underlying sediment. (Photo courtesy of Deepsea Ventures, Inc.)

Environmental Impact

The beginning of commerical interest in manganese nodules coincided with the blooming of environmental awareness in the United States — that is, in the late 1960s and early 1970s. The fledgling industry offered an opportunity to demonstrate the potential of undertaking a major resource development program that would take environmental needs into consideration in the very early stages. Since 1968, there have been those in the ocean mining industry, government, and academia who have recognized and acted upon this unique opportunity. With their foresight and guidance, plans were devised to assemble all interested parties and to permit open and frank discussions through all stages of the technological development. This has resulted in cooperative efforts (involving government, industry, academic, and environmental representatives) in the study and evaluation of the effects that marine mining will have on the environment. The core of this cooperation is the Deep Ocean Mining Environment Study (DOMES I/DOMES II) program and the follow-on preparation of the Final Programmatic Environmental Impact Statement and the Five-Year Research Plan devised by the National Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce. This spirit of cooperation has been very encouraging and continues to prevail; it provides a model for the development of other new industries.

Much remains unknown concerning the impact of ocean mining on the seabed and water column. Joint environmental research programs with NOAA and among consortia (Table 1) have been mandated by Congress and will be continued in the future.

Unfortunately, the terrestrial mineral deposits from which some metals can be produced are located in remote, undisturbed environments. In the United States, a dilemma exists regarding the desire

Table 1. Composition of major ocean mining consortia and related data.

Participants	Parent Company (or Components)	Country of Origin of Parent Company	Share of Participation (%)*
OCEAN MINING ASSOCIATES (Formed May 1974). Estimated expenditures to date: $80 million.			
Essex Minerals Co.	U.S. Steel Corp.	U.S.	25
Union Seas, Inc.	Union Miniere	Belgium	25
Sun Ocean Ventures	Sun Company, Inc.	U.S.	25
Samim Ocean, Inc.	Ente Nazionale Idrocarburi (ENI)	Italy	25
KENNECOTT CONSORTIUM (Formed Jan. 1974). Estimated expenditures to date: $50-60 million.			
Kennecott Minerals Company	Sohio (British Petroleum owns majority of stock)	U.S.	40
RTZ Deepsea Enterprises, Ltd.	Rio Tinto-Zinc Corp., Ltd.	Britain	12
Consolidated Gold Fields, PLC	Same	Britain	12
BP Petroleum Development, Ltd.	British Petroleum Co., Ltd.	Britain	12
Noranda Exploration, Inc.	Noranda Mines, Ltd.	Canada	12
Mitsubishi Group	Mitsubishi Corp. Mitsubishi Metal Corp. Mitsubishi Heavy Industries, Ltd.	Japan	12
OCEAN MANAGEMENT, INC. (Formed Feb. 1975). Estimated expenditures to date: $45-50 million.			
Inco, Ltd.	Inco, Ltd.	Canada	25
AMR (Arbeitsgemeinschaft Meerestechnischgewinnbare Rohstoffe)	Metallgesellschaft AG Preussag AG Salzgitter AG	West Germany	25
SEDCO, Inc.	Same	U.S.	25
Deep Ocean Mining Co., Ltd. (DOMCO)	23 companies	Japan	25
OCEAN MINERALS COMPANY (Formed Nov. 1977). Estimated expenditures to date: $120 million.			
Amoco Ocean Minerals Co.	Standard Oil of Indiana	U.S.	30.7
Lockheed Systems Co., Inc.	Lockheed Aircraft Corp.	U.S.	30.7
Ocean Minerals, Inc.	Lockheed Missiles and Space Co., Inc.	U.S.	
	Billiton BV (Royal Dutch/Shell group)	Netherlands	30.7
	BKW Ocean Minerals (subsidiary of Royal Bos Kalis Westminster Group, NV)	Netherlands	7.9

AFERNOD (Association Française pour l'Etude et la Recherche des Nodules)
Formed 1974, France. Estimated expenditures to date: $45 million ($38 million between 1980 and 1982).

Participants

Centre National pour l'Exploitation des Océans (CNEXO)
Commissariat à l'Energie Atomique (CEA)
Société Métallurgique le Nickel (SLN)
Chantiers de France-Dunkerque

DEEP OCEAN MINERALS ASSOCIATION (DOMA)
Formed 1974, Japan (as public corporation)

Members

Trading Companies

C. Itoh and Co., Ltd.
Kanematsu-Gosho, Ltd.
Maruheni Corp.
Mitsubishi Corp.
Mitsui and Co., Ltd.
Nichimen Co., Ltd.
Nissbo Iwai Corp.
Sumitomo Corp.

Mining and Metallurgy Companies

Dowa Mining Co., Ltd.
Furukawa Company, Ltd.
Japan Metals and Chemicals Co., Ltd.
Mitsubishi Metal Corp.
Mitsui Mining and Smelting Co., Ltd.
Nippon Mining Co., Ltd.
Nippon Yakin Kogyo Co., Ltd.
Nittetsu Mining Co., Ltd.
Pacific Metals Co., Ltd.
Sumitomo Metal Mining Co., Ltd.

Members

Shipping Companies

Iino Kaiun Kaisha, Ltd.
Mitsui O.S.K. Lines, Ltd.
Nippon Yusen K. K.

Cable Companies

The Fujikura Cable Works, Ltd.
Sumitomo Electric Industries, Ltd.

Electric Appliances

Nippon Electric Co., Ltd.
Victor Co. of Japan, Ltd.

Fisheries

Kyokuyo Co., Ltd.

Members

Shipbuilding and Heavy Industries

Hitachi Shipbuilding and Engineering Co., Ltd.
Ishikawajima-Harima Heavy Industries Co., Ltd.
Kawasaki Heavy Industries Co., Ltd.
Mitsubishi Heavy Industries, Ltd.
Mitsui Engineering and Shipbuilding Co., Ltd.
Nippon Kokan K. K.
Sumitomo Heavy Industries, Ltd.
Ebara Engineering, Co., Ltd.
Meidensha Electric Co., Ltd.

Steel Companies

Kawasaki Steel Corp.
Kobe Steel, Ltd.
Nippon Steel Corp.
Sumitomo Metal Industries, Ltd.

*Shares of participation are as of February 1982. It is possible that these shares may vary over time.

Sources: Ocean Economics and Technology Branch of U.N. Department of International Economic and Social Affairs. Also, J. K. Amsbaugh, Ocean Mining Associates, "The Ocean's Contribution to the Solution of the U.S. Strategic Minerals Crisis," a paper presented at a meeting of the American Metals Society Sept. 22, 1981.

This Deepsea Ventures testing pond at Gloucester Point, Virginia, is designed to duplicate the physical characteristics of the ocean floor and to simulate the movement of a collecting device as deployed from a mining ship. Artificial manganese nodules are made from baked clay and vermiculite and distributed in the pond on top of clay layers. A dredge head collects the "nodules" as it moves the length of the pond, attached to the carriage at the far end. (Photo by William T. Allen, Deepsea Ventures, Inc.)

to preserve the natural environment and at the same time fulfill the urgent need to locate new sources of raw materials. Complicating factors are the depletion of higher-grade resources and the resultant move toward mining deposits where the metal is in lower concentration. Compared to a richer deposit, mining a low-grade deposit requires moving more rock for the same amount of metal. Open pit or strip mining are typically the most economical methods for mining these lower-grade ores. This type of mining results in major and unsightly upheavals of the natural terrain. The proposed solution of progressive restoration is, in many instances, considered unacceptable. This is particularly true when areas of unique scenic beauty are disturbed or destroyed or where delicate ecosystems are involved. Industry's near-term efforts can rehabilitate, but not restore.

The development of the deep-ocean nodule resource offers an alternative to exploiting some terrestrial land deposits. Fortunately, the nodules are typically surficial deposits and do not require moving massive amounts of sediment for recovery. This is not to suggest that mining the nodules will be without environmental impact. All mining disturbs the environment. However, in the case of seabed mining, an appropriate and balanced approach to mining can be effective while leaving large adjacent areas undisturbed. The general nature of the seafloor will be preserved to provide potential repopulation areas for the biota.

Right of Access

To proceed with confidence, the ocean mining industry needs assurance of legal access to deep seabed mineral resources and security of contract for the mining period. In an effort to provide a legal framework for mining in international waters, tremendous efforts have been made to satisfy the interests of countries throughout the world. Although the ideal situation is far from realized, the United States has stepped forward with domestic ocean mining legislation. Conflicts over jurisdiction are receiving significant attention and resolution is being pursued through several channels.

Presently, the marine mining industry is trying to acquire rights to explore and mine nodule deposits that were discovered at great expense during the 1970s. These deposits must be sufficient in size so that further intensive exploration may isolate an area large enough to support mining operations for 20 to 30 years. This process includes the identification of such exploration tracts and the filing of exploration licenses.

In June, NOAA published regulations that govern the formal processing of domestically filed applications for exploration licenses. Such applications were filed earlier in 1982 by Ocean Mining Associates (OMA), Ocean Minerals Company (OMCO), Ocean Management, Inc. (OMI), and the Kennecott Consortium (K/CON). The NOAA regulations set forth a methodology for encouraging the voluntary resolution of conflicts among applicants. Provisions exist in the Department of Commerce's administrative law courts to force resolution, in the absence of mutual agreement, of domestic conflicts. Where an international conflict exists, two mechanisms for resolution are available: 1) all domestic consortia have joined with AFERNOD,

a French consortium, in a private arbitration agreement that, under its terms, can resolve any international conflicts arising among the signatories, and 2) any international conflict remaining unresolved after a voluntary arbitration period will be settled according to conflict resolution procedures agreed to by the United States and any other nations who have entered into "reciprocation" agreements with the U.S.

Security of Tenure

Corporate and banking industry financial officers have the words "security of tenure" engraved on their hearts and in their minds. They are comfortable with economic and technical risks but do not like to contemplate political risk. Expropriation by dictatorships or nationalist governments is ground to be avoided like quicksand. No rational financial mind will enjoy dealing with the unsettling political climate represented by an independently financed, highly discretionary, intensely political agency such as the International Seabed Authority created at the recently concluded Third United Nations Conference on the Law of the Sea (UNCLOS III). This Authority will not be development-minded. On the contrary, it will be devoted to protecting land-based mineral producers in developing countries from perceived competitive pressures raised by ocean mining. Thus, the Authority will function from a base of total discretionary control over the ocean miner's entry into and operations upon the deep seabeds. This control will be coupled with the power of economic manipulation by means of a complex and burdensome fabric of royalties and/or taxes and fees, production and price controls, technology transfers, and training obligations.

In contrast to the present Law of the Sea concept, what is really needed for rational development is a stable legal climate, allowing predictability as to: resource access, tenure during pre-mining exploration and during commercial operations, and investment security (continued economic viability of investment).

Managing an International Consortium

The mining industry is undergoing a radical change in its economic life. Demand and market prices are drastically depressed at a time when capital and operating costs are soaring. Sources of equity capital and debt financing for the industry are shifting. Many new investors in the "hard rock" industry are unfamiliar with hard mineral economics, that is, the cyclical nature of the market.

In the ocean mining field, these conditions have given rise to consortia composed of companies mixed in terms of: country of origin, industrial concentration (for example, petroleum, copper, nickel, cobalt, steel, and aircraft), and source of equity (public or private).

The member companies of the consortia have different management traditions, economic strengths, policy mechanisms, and commercial objectives, and therefore encounter many internal roadblocks and detours. In the future, there probably will be a realignment into consortia composed of different partners than exist today.

Future Contribution of Ocean Mining

It has often been said that more is known about the moon's backside than about the ocean's bottom. The development of commercial ocean mining by private industry may very well contribute to an about-face here.

It is generally known that several international joint ventures have been formed to develop the nodule resource. These have become necessary in order to share the very great costs and the commercial, technical, and political risks associated with the development of the new technology needed to recover minerals from vast ocean depths in very hostile and isolated environments. Scientific research has been an early beneficiary of these initial international activities and, as mining development continues, should benefit even further. Advanced survey tools and techniques associated with nodule resource assessment and mining development, as well as environmental impact data collection, have resulted in significant contributions to scientific research, particularly in the abyssal ocean regions.

Although international jurisdiction of ocean resources is not yet resolved, exploration for the resources has encouraged progress toward such resolution through international recognition of the conflicts involved.

As we gain knowledge, the risks of deep-ocean mining become better defined. Reducing the risk is not simply a matter of expanding research efforts, but also of determining the world's future resource needs and improving the international economic and political climate.

J. K. Amsbaugh is President of Ocean Mining Associates (OMA), a consortium consisting of the Sun Company, Inc., and the U.S. Steel Corporation (U.S. companies), Union Miniere (Belgian), and Samim (Italian). Jan L. Van der Voort is the Market Research Analyst for OMA.

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The Law of the Sea: Myths and Realities

by Bernardo Zuleta

The adoption on April 30, 1982, of the Convention on the Law of the Sea by an overwhelming majority that included all the regions of the world, all the different legal systems, a large number of industrialized nations, and the vast majority of coastal, geographically disadvantaged, and landlocked nations, marked the culmination of almost 14 years of very serious work that involved one of the most remarkable assemblies of international jurists and diplomats ever convened in recorded history.

The Conference, as is well known, made every effort to achieve general agreement in order to have the Convention adopted by consensus after giving one particular participant, the United States, the opportunity to re-examine for more than a year the agreements already reached previously with its participation and consent.

Bernardo Zuleta, Under Secretary General of the United Nations.

The Conference had decided during its tenth session on a rigid calendar and program of work that would make it possible under any circumstances to begin the formal decision-making process no later than April 23, so that the Convention could be adopted at the latest on April 30. This decision had been endorsed unanimously by the General Assembly of the United Nations, and therefore it should have come as no surprise that the Convention was indeed adopted on the date indicated, though one of the major protagonists had formally requested a vote on the adoption itself.

In addition to the United States, three delegations voted against adoption, on grounds that obviously had nothing to do with the U.S. position. Among the 17 delegations that abstained, nine, including the Soviet Union, have indicated that they will sign the Convention when it is opened for signature in Caracas. All the delegations that abstained made it clear that their abstentions did not prejudge decisions to be made by their governments regarding the signing of the Convention. The positive votes included three nations whose companies can easily be described as pioneers in seabed mining and many other industrialized nations whose interests in the metal markets are well known.

The Myths

The first myth that has to be dispelled with regard to the Law of the Sea Convention is that it has been sunk by the decision of one country, as has been suggested by some writers.* There are legions of international instruments that have come into force and have been implemented without the participation of one or more of the most industrialized nations. The United Nations system itself can provide examples of major international organizations whose membership does not include all the nations that are usually referred to as "major

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*See, for example, "Underwater Treaty" by Daniel D. Nossiter, *Barron's*, July 26, 1982.

powers." This misconception is based on another series of myths that have been deliberately spread around in order to discredit the work of the United Nations in the field of the Law of the Sea.

There is, for instance, the tale about the legal concept of the common heritage having been invented, out of nowhere, during one session of the General Assembly in 1967. Any serious student of international law knows that the idea was suggested before the turn of the century by a famous French publicist, Monsieur de Lapradelle, surfaced again many years later in a speech by Prince Wan Waithayakon of Thailand, President of the First United Nations Conference on the Law of the Sea, and became a major point of U.S. policy in 1966 when President Lyndon B. Johnson warned the international community against the creation of "a new form of colonial competition among the maritime powers."

There is also the myth about the Law of the Sea Conference having engaged in a duo of polemics, those between North and South and those between East and West.* Anybody familiar with the work of the Conference would readily agree that nations did not coalesce within the traditional regional or political alignments but grouped themselves to face specific problems and to protect clearly identifiable interests. Coastal nations wanted a legal regime that would allow them to manage and conserve the biological and mineral resources within their national jurisdiction. Archipelagic nations wanted to obtain recognition for the new regime of archipelagic waters. Landlocked nations were seeking general rules of international law that would grant them transit to and from the sea and certain forms of access to the living resources of their neighboring nations. Some industrialized nations that do not have certain mineral resources within their jurisdiction wanted guaranteed access to the seabed mineral resources beyond national jurisdiction, within a predictable legal framework. Countries that produce these same minerals in their territories, many of them industrialized nations, wanted assurances that the seabed production of the minerals would not undermine their economies or result in a *de facto* monopoly. Developing countries wanted to be more than silent witnesses to the acquisition of new knowledge of the oceans, so that marine science and technology could be put at the service of all instead of withheld by a limited number of very wealthy countries. Practically all nations wanted to preserve the freedoms of navigation, commerce, and communication, while nations bordering straits wanted to ensure that free passage would not result in damage to their marine environments or threats to their national security. And, finally, mankind as a whole needed to ensure that a new legal regime would safeguard the marine environment against depredation or irrational use of nonrenewable resources, the discharge or dumping of noxious substances into the oceans, or the so-called scientific tests that could affect the delicate balance of marine life.

*See, for example, Professor L. F. E. Goldie, Report of the Fifty-Eighth Conference of the International Law Association, Manila, p. 311.

The Realities

But far more important than dispelling such myths is to concentrate on the realities that the international community will have to face as a consequence of the adoption of the new treaty, as they may affect the prospects for exploration and exploitation of the resources that lie beyond all limits of national jurisdiction.

In addition to the Convention itself, the Conference adopted four resolutions, of which two are of immediate concern to the seabed mining industry: the resolution establishing the Preparatory Commission and the resolution governing preparatory investment in pioneer activities relating to polymetallic nodules.

The Preparatory Commission must be convened by the Secretary General of the United Nations not later than 90 days after the signature by 50 nations, and a Convention that has been adopted by 130 votes* is likely to be signed by at least half that number when the instrument is opened for signature. Nations that have signed the Convention or acceded to it will be full participants in the deliberations of the Commission, while signatories of the Final Act may participate in the deliberations as observers but will not be entitled to participate in the making of decisions.

One of the first tasks of the Preparatory Commission will be the registration of pioneer investors, certified by signatories of the Convention. Such registration will give the pioneer investor the exclusive right to carry out activities in the area allocated to it. The Preparatory Commission will have to determine that every application covers an area sufficiently large and of sufficient estimated commercial value to allow two mining operations. Guidelines will have to be established for the commerical evaluation, taking into account, among other things, the information provided by the applicant relating to mapping, sampling, the density of the nodules, and the composition of metals in them. Certifying nations (signatories of the

*The results of the vote to adopt the Law of the Sea Convention:
Against — Israel, Turkey, United States, Venezuela.
Abstaining — Belgium, Britain, Bulgaria, Byelorussia, Czechoslovakia, East Germany, Hungary, Italy, Luxembourg, Mongolia, Netherlands, Poland, Soviet Union, Spain, Thailand, Ukraine, West Germany.
In favor — Afghanistan, Algeria, Angola, Argentina, Australia, Austria, Bahamas, Bahrain, Bangladesh, Barbados, Benin, Bhutan, Bolivia, Botswana, Brazil, Burma, Burundi, Cameroon, Canada, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Congo, Costa Rica, Cuba, Cyprus, Democratic Kampuchea, Democratic Yemen, Denmark, Djibouti, Dominican Republic, Egypt, El Salvador, Ethiopia, Fiji, Finland, France, Gabon, Ghana, Greece, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Iceland, India, Indonesia, Iran, Iraq, Ireland, Ivory Coast, Jamaica, Japan, Jordan, Kenya, Kuwait, Lao People's Democratic Republic, Lebanon, Lesotho, Libya, Liechtenstein, Madagascar, Malawi, Malaysia, Mali, Malta, Mauritania, Mauritius, Mexico, Monaco, Morocco, Mozambique, Namibia (United Nations Council for), Nepal, New Zealand, Nicaragua, Niger, Nigeria, North Korea, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Portugal, Qatar, Romania, Rwanda, Saint Lucia, Saint Vincent, Samoa, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Singapore, Somalia, South Korea, Sri Lanka, Sudan, Suriname, Swaziland, Sweden, Switzerland, Syria, Tanzania, Togo, Trinidad and Tobago, Tunisia, Uganda, United Arab Emirates, Upper Volta, Uruguay, Viet Nam, Yemen, Yugoslavia, Zaire, Zambia, Zimbabwe.

Convention who are sponsoring pioneer investors) must resolve their conflicts by negotiation, failing which they must submit their competing claims to binding arbitration.

The Preparatory Commission also will have to prepare draft rules, regulations, and procedures to enable the future Seabed Authority to commence its functions. The regulations will cover a wide range of subjects, such as size of mining areas; duration of operations; performance requirements; qualification standards for applicants; environmental regulations; uniform, nondiscriminatory costing and accounting rules; financial incentives; guidelines to determine whether and when a seabed mining technology or its equivalent can be obtained on the open market; and guidelines to establish fair and equitable prices for such technology.

One can easily imagine that many nations which are interested in sponsoring pioneer activities without having to face legal challenges will find out that it is in their interest to be entitled to participate in the decision-making process of the Preparatory Commission and in the machinery for the settlement of conflicts with regard to mining sites, so as to obtain for their companies the exclusive right concerning a specific mine site. Though no seabed mining consortium is yet prepared to undertake commercial recovery or to embark on the design and testing of smelting plants, there is clear evidence that the continuation of site-specific research and development activities will require the necessary legal and political assurances that can hardly be found outside the framework of the Convention.

How the work of the Preparatory Commission will affect the process of ratification and entry into force of the Convention is a question that has to be closely examined. In many instances, nations signing the Convention with a view to fully participating in the work of the Preparatory Commission are likely to defer their decisions on ratification until they are satisfied that they can live with the rules, regulations, and procedures adopted by the Commission, which will apply provisionally upon entry into force. Other nations will decide on ratification by taking into account their own priorities with regard to ocean space, which are not necessarily related to seabed mining activities. Developing coastal nations are likely to be influenced by their interest in deriving full benefit from the establishment of the exclusive economic zone. Nations with broad continental shelves will have an interest in an early entry into force of a treaty that will give precise limits to their legal rights with regard to that portion of the shelf that extends beyond 200 miles. Landlocked nations are likely to take into consideration their transit rights and their participation in the fisheries of neighboring countries. Archipelagic nations will want to see the new provisions on archipelagic water become conventional law. And nations bordering closed or semi-enclosed seas will find it easier to establish patterns of cooperation under a common legal framework.

Out in the Cold

It is, therefore, possible that the Convention may enter into force (upon its ratification by 60 countries) before the first seabed mining operator is ready to embark on actual exploitation of a mine site. Should this happen, many companies, their boards of directors, and their bankers will have to face difficult decisions. They know full well that, although the seabed mining regime is less than perfect, it is workable. Depending upon metal-price prospects, some of the deep seabed mining companies would prefer to operate under the treaty and would encourage their governments to enable them to do so.

At that moment, the question of the functioning of the Enterprise, the operative arm of the Seabed Authority, will become relevant. If nations and private investors are unable to finance an undersea mining project, those responsible for the management of the Enterprise are not likely to embark on a money-losing venture. If, on the contrary, investments in seabed mining on one side of the "parallel system" become feasible, the Enterprise is likely to become a rather attractive partner, at least for some stages of a seabed mining project. One could speculate, for instance, that developing countries whose geographical locations make them attractive sites for the smelting processes would give the Enterprise a favorable treatment which they would not be ready to give to other nations or to private companies.

All of these considerations are speculative in character but are based on experience gained from the work of the Conference itself and on the provisions of a legal text which has been adopted and is likely to come into force. But there is another point which is quite evident to anybody who has ever been associated with the work of the Third United Nations Conference on the Law of the Sea: regardless of how many countries will, in due time, become parties to the Convention, the law of the sea will not revert to customary law, as perceived by a limited number of publicists in only one of the world's legal systems.

As Dr. J. Finnis of the University College of Oxford has very aptly remarked, "the analysis of the relation between practice, *opinio juris*, and resultant norm is typically found to be question-begging or paradoxical." He suggests that, based on the classical analysis, "a customary norm could come into existence only by virtue of the necessarily erroneous belief that it is already in existence."*

I feel confident that the vast majority of countries *and* private investors would like the Law of the Sea to be real international law — not simply legal jargon based on the writings of a few lawyers who adhere to a legal doctrine that has no support in the international community.

Bernardo Zuleta is Under Secretary General of the United Nations and Special Representative of the Secretary General to the Third United Nations Conference on the Law of the Sea. He is a native of Colombia. (The opinions expressed in this article are made in a personal capacity and do not necessarily reflect the official views of the Secretariat of the United Nations.)

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*Dr. J. Finnis, Report of the Fifty-Eighth Conference of the International Law Association, Manila, p. 200.

Some abyssal animals inhabiting the area of the Pacific Ocean, southeast of Hawaii, which is likely to be mined first for manganese nodules. The nodules in these photos are nearly buried in the sediment. At top, a spined sea cucumber (class Holothuroidea) makes its way across the ocean floor. In the middle photo, two sea cucumbers of another species lie beside a brittle star (order Ophiurida). And in the bottom photo, a shrimp (order Decapoda) swims over another brittle star. (Photos courtesy of Deepsea Ventures, Inc.)

The Environmental Aspects of Deep Ocean Mining

by Clifton Curtis

The oceans, covering more than 70 percent of the earth's surface, play a critical role in maintaining a livable environment. Our natural deep-sea and near-shore marine systems existed for millions of years before the appearance of humans. Until recently, protection of the marine environment has been achieved by default, because the deep sea was too remote to be affected greatly by human activity.

We all agree that human activities can have a profound adverse impact on the marine environment and its resources. Pollution from tankers and offshore oil and gas deposits, land-based pollution of near-shore areas, and the dumping of wastes in the ocean have denigrated the marine environment. With deep seabed mining, we are at the front end of the development of a new technology. Our intervention by exploitation, and even by vigorous exploration, of manganese nodules and polymetallic sulfides will disrupt the marine environment. As with other human activities that interact with deep-sea and coastal systems, decisions to proceed with deep seabed mining must be accompanied by actions that will minimize the environmental risks and provide for the suspension of operations where unacceptable harm appears.

National and international laws, rules, and regulations will provide the legal, political, and regulatory framework that will determine the manner in which we seek to preserve, protect, and responsibly utilize our vital marine resources. Their effective enforcement — and an environmentally conscientious attitude on the part of industry and governments — will be crucial.

How concerned must we be with the environmental impacts associated with deep seabed mining? At present, existing scientific understanding of deep-sea systems and processes is rudimentary, and present knowledge concerning the possible environmental impacts of deep-sea mining is very limited. Considerable research has been done in

recent years, but we have barely touched the tip of the iceberg. Even the ecosystems baseline data, particularly for benthic communities, are very sketchy. Studies of the actual effects of mining have been limited to a few short-term tests at the surface and the bottom. No long-term studies of any sort have been conducted. No tests of anything approaching full-scale operations have been possible.

Thus, at this time no one really knows the ultimate environmental implications of deep-sea mining. If we accept our responsibilities as trustees of the ocean for the future of humankind, it follows that a comprehensive system of environmental management is required. Deep-sea mining must move forward with extreme caution as we seek the necessary answers.

Possible Environmental Impacts

Adverse environmental impacts will occur at or near the seafloor, in the water column, at the surface, and as a result of processing at sea or on land. Since studies concerned with the environmental impacts of manganese nodule mining are more advanced than those for polymetallic sulfides, this article addresses manganese nodule mining as its point of reference. Nodules most likely will be recovered from the seabed by means of a collector, which will be pulled or driven along the seabed. Benthic biota will be destroyed, both through direct disturbance and through the creation of a sediment plume that will affect a much larger area. Nodules raised to the surface will be accompanied by deep ocean water and sediment. The dumping of any bottom water, sediments, and nodule fragments on the surface will create a plume that may take years to settle downward. The effect of the plume is unknown; it could be detrimental to phytoplankton and other levels of the food chain. Processing at sea could have harmful environmental consequences as the result of the disposal of immense amounts of waste with metal tailings and the intentional or accidental discharge of highly caustic reagents: processing in or near coastal areas and the consequent pollution could well change the basic character of coastal areas.

The Ocean Bottom

Recent research suggests that the benthos sustains more diverse and important resources than was previously thought. But only the most limited information exists regarding these deep-sea benthic communities, and virtually nothing is known about the benthic relationship with the upper ocean layers or the possible impacts of a) stirring up and substantially disturbing the benthos or b) bringing these organisms and associated sediments to the surface. As a starting point, however, we do know that benthic communities are ill-adapted to environmental changes of any kind, since temperature, salinity, chemical concentrations, and most other characteristics are virtually constant at any given location.

Mining will affect the deep-ocean floor substantially. The scraping or sucking of the bottom will kill bottom-dwelling organisms. A 1,000-ton-a-day nodule-mining machine probably will move more than 4,000 tons of sediment. Much of this sediment will be quickly redistributed on the ocean floor, killing whatever organisms are there. However, a cloud of suspended sediment (the benthic plume) will be formed as a result of these operations. Depending on particle size, this material may take from months to years to settle. This suspended sediment could be lethal to benthic fauna in areas far beyond the actual site of mining operations.

Another unknown is the recolonization rate for disturbed areas. Benthic community metabolism in the deep sea may be three orders of magnitude slower than in shallow water. Because of the slow growth of nodules, fauna directly or indirectly dependent on nodules could take more than 1,000 years to return to natural abundance levels in mined areas.

The Water Column

Nodules, accompanied by some quantity of sediment, living organisms, and water, will be transported to the surface. Whatever mining method is used, some water and sediment will be released along the upward path into the water column.* Assuming all materials are discharged at or near the surface, a plume will be formed by the particles. It remains unclear how long it will take these particles to settle, although they will be dispersed laterally quite quickly.

Recent Deep Ocean Mining Environmental Studies (DOMES), conducted by the National Oceanic and Atmospheric Administration (NOAA), indicate that surface plumes may not present as much of an adverse environmental effect as first thought. However, this conclusion is very preliminary and will need to be substantiated through further research and monitoring.

The disposal of deep-ocean sediment and bottom water in the surface areas could result in several types of environmental impacts. The upper layers of the ocean are where phytoplankton exist, where photosynthesis takes place, and where part of the earth's oxygen is produced. Depositing sediment on top of this zone would limit light penetration. This could result in a substantial reduction of phytoplankton and the impairment of photosynthesis, thus affecting the early stages of the food chain. And as sediment sinks, bacteria attached to it may use oxygen in oxygen-scarce zones, adversely affecting organisms there.

In addition to the impact on phytoplankton production, early DOMES studies (those undertaken five or six years ago) suggest that surface discharge of mining wastes may also result in long-term exposure of marine biota to heavy metals. Further studies should consider whether such discharges could cause accumulation of toxic metals in the food chain,

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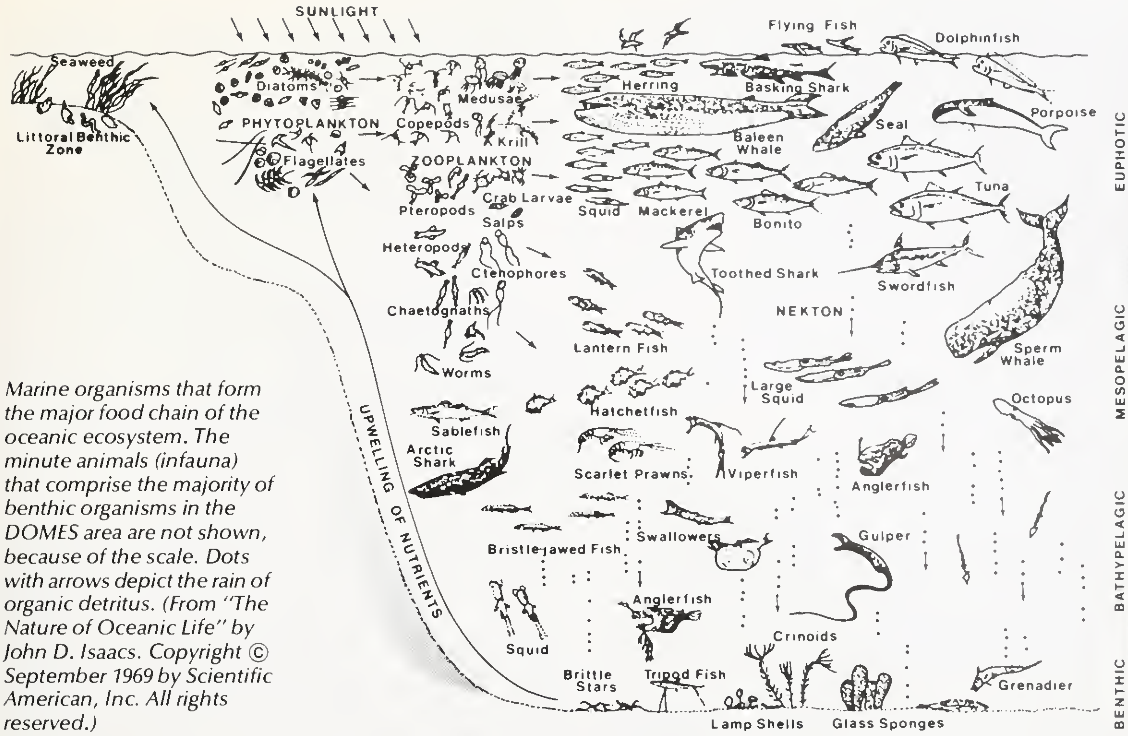
*More sediment is likely to come to the surface with the suction method. Although it is probably possible, technologically, to pipe most sediment back down for discharge at intermediate depths, it is unknown whether that would be preferable environmentally.



Marine organisms that form the major food chain of the oceanic ecosystem. The minute animals (infauna) that comprise the majority of benthic organisms in the DOMES area are not shown, because of the scale. Dots with arrows depict the rain of organic detritus. (From "The Nature of Oceanic Life" by John D. Isaacs. Copyright © September 1969 by Scientific American, Inc. All rights reserved.)

resulting in significant depletions of zooplankton stocks and impacts on tuna and other fish species. Marine mammals and seabirds that depend on these stocks for their food also would be affected.

Although NOAA has recently indicated that it no longer believes trace metals present a significant cause for concern, it intends to verify this view through further research and, if necessary, during mining systems tests.

Some proposed mining locations are also areas of fishing for tuna and other species. It is unclear whether fishing and deep-sea mining will be compatible. Studies have shown that tuna are attracted to discontinuities of the sort that ocean mining would create. Their spawning periods and residence areas could be influenced by this attraction, with the risk of substantial destruction of larval forms by the plumes. To date, however, research and monitoring has not yet determined whether the sediment discharged from the surface will be detrimental to commercial fish stocks, either directly or indirectly through its effect on the food chain.

DOMES also has noted that environments vary within the proposed mining area. Thus, site selection could be a critical step. For example, wastes from improperly selected mine sites could adversely affect coral reefs and their associated fish communities. Impacts with far-reaching consequences might disrupt normal migratory patterns.

Processing

Although initial processing operations are likely to be land-based, some specialists have suggested that at-sea processing ultimately offers the best solution to the expense of transport and the disposal of tailings. Processing at sea would probably involve large Ocean Thermal Energy Conversion (OTEC) plants to produce the necessary energy. These plants could have substantial environmental implications in and of themselves. Even if a conventional fossil or nuclear energy plant were used, there could be substantial air and water pollution risks, with resultant impacts on various organisms.

At present no empirical data exists on the effects of marine disposal of processing wastes. We have no real idea of the seriousness of the problem. Two of the most significant environmental considerations involve toxicity and bioaccumulation. Whether the wastes are dumped into the deep ocean, on the continental shelf, or near shore, the toxic metals, other trace elements, and toxic reagents used in the processing could have serious impacts on organisms and the ecosystem. DOMES has found that acids, toxic metals, and trace elements, upon reaching critical concentrations, can kill organisms in the vicinity of the discharge, including tuna and other commercial species.

In the deep ocean, the extent of this impact would be magnified if such species were attracted to mining vessels or associated plumes. In near-shore areas, the potential for adverse impacts is increased by the heavy use of those areas by fish for spawning and nursery grounds, by large concentrations of phytoplankton and other nutrients, and by the existence of shorter food chains leading to human consumption.

Management Framework

Efforts to adequately assess and control the adverse environmental impacts of mining activities are unlikely to be effective unless performed under a broad mandate of protection and scientific integrity. The ultimate objective should be to create a regulatory entity with the responsibility, authority, staff, funds, and expertise needed for maximum protection of the marine environment. Governments, international organizations, and private parties must join to create a management structure along the following lines:

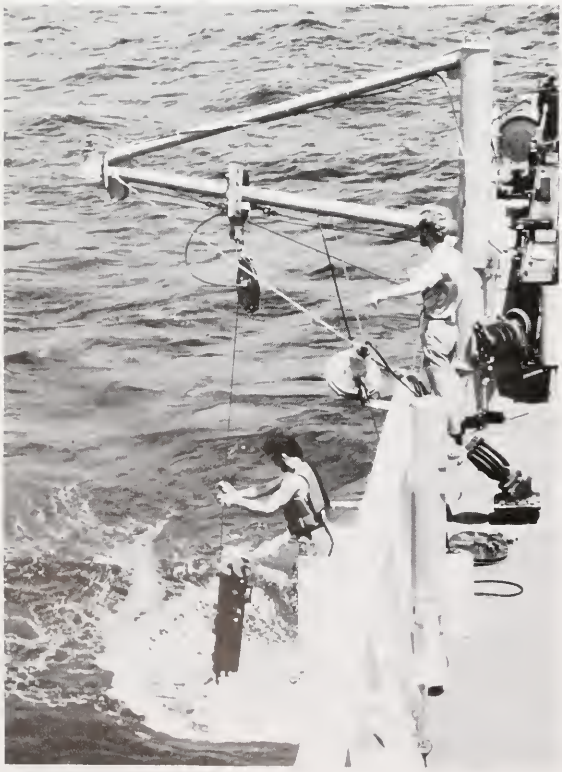
1) *Baseline studies, monitoring, and assessment should be a principal component of the system, and mining applicants should be required to conduct research at proposed sites;*

2) *The resulting data should be used to develop standards, measures, and contract terms for environmental protection that reflect the genuine needs of the oceans, and to establish regulations for worker health and safety. The preparation of site-specific environmental impact statements should be undertaken to assist decision-makers in developing such standards and measures;*

3) *Measures should be enforced without regard to political exigencies; and conflicts of interest between development and regulation must be avoided whenever possible. This requires adequate representation of the noneconomic interests in the decision-making process, including effective public participation mechanisms, and a bureaucratic separation of the development and protection functions;*

4) *Environmental rules, regulations, and measures based on new data and research should be applied to ongoing mining and processing operations and should include environmentally sound criteria for issuance of suspension orders and license revocations; and*

5) *National and international conservation programs should be established for the critical minerals in question, so that excess mining can be avoided.*



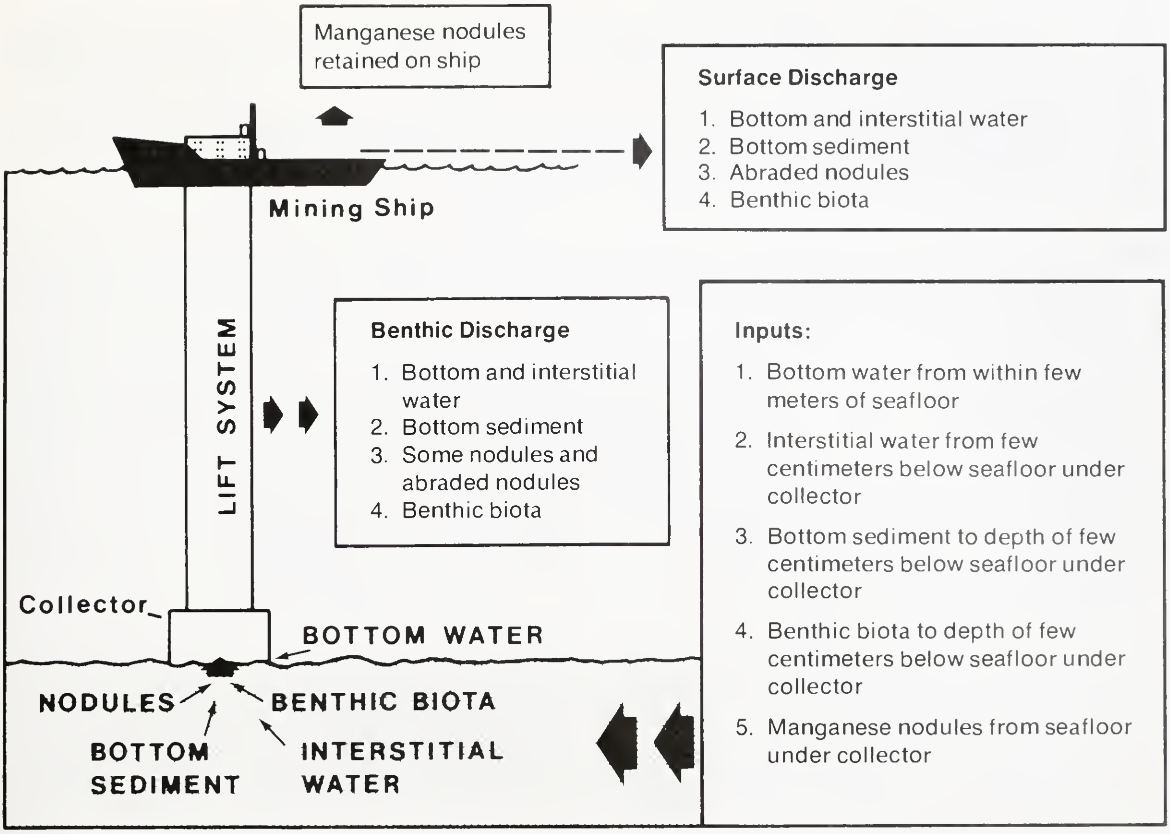
Seawater samples being taken from the ocean floor during the National Oceanic and Atmospheric Administration's Deep Ocean Mining Environmental Study (DOMES). (Photo courtesy of NOAA)

Law of the Sea Convention

During the last decade, the United States and 150 other nations have devoted substantial time and resources to developing a Law of the Sea (LOS) Treaty that would provide a regulatory framework for a wide range of marine-related activities. The provisions that deal with deep seabed mining became, in recent years, the most controversial part of the Convention. And the controversy continues, with the Convention scheduled to be opened for signature in Caracas, Venezuela, in December, 1982. At the eleventh and final session of the Conference, which came to a close at the United Nations on April 30, the text of the Convention was adopted by 130 nations, with 17 abstaining and four voting against. The four voting against were Israel, Turkey, Venezuela, and the United States. In early July, President Reagan formally announced that the United States would not sign the Convention because "the deep seabed mining part of the Convention does not meet United States objectives."

While the environmental provisions in the Convention are not as strong as some participants in the negotiations had hoped for, the widespread acceptance and implementation of the Convention's environmental provisions are fundamental to the preservation of the marine environment. The Convention set the groundwork for a comprehensive system of protection. In total, the environmental provisions constitute a significant advance over what customary international law now provides, and the international consensus reflected in the Convention could lead to sound strategies and solutions in the future. It is certainly a large step forward for virtually all nations of the world to have agreed on basic obligations and duties to protect what are essentially common resources.

The Convention contains many principles and obligations for protection of the marine environment from deep-sea mining activities. They include: 1) reviewing detailed work plans; 2) supervising mining activities; 3) preparing environmental assessments of activities in the mining area; 4) making recommendations to the Council regarding protection of the environment; 5) formulating and reviewing rules, regulations, and procedures, and



The input and output of a hydraulic mining system.

recommending such amendments as are "necessary and desirable"; 6) establishing a regular monitoring and research program, with one focus being to "ensure that existing regulations are adequate"; and 7) recommending that emergency orders be issued, including those for "suspension or adjustment of operations" to prevent serious environmental harm. Once 50 nations have signed the Convention, a Preparatory Commission will draft the detailed rules, regulations, and procedures to implement these requirements. It is expected that the Convention will be signed by at least 50 nations by the spring of 1983 (the treaty comes into force when 60 countries have signed it).

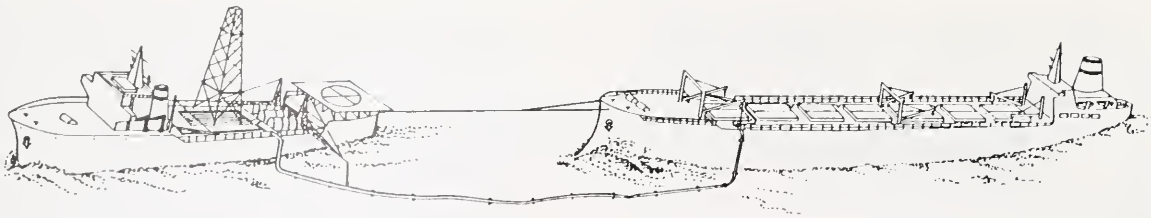
When the Convention is viewed as a whole, the balance of its wide range of provisions is in the best interest of the United States. The Reagan Administration should reconsider its decision not to sign. Signing would provide the United States with an important means of influencing mining standards and practices by allowing a U.S. delegation to participate in the work of the Preparatory Commission. After those rules and regulations are drafted, the U.S. Senate would then have the opportunity to review the adequacy of the Convention prior to giving its "advice and consent" to ratification.

Other Arrangements

A small group of industrialized nations, including the United States, has been negotiating a Reciprocating States Agreement (RSA) which would provide a mechanism to resolve overlapping deep seabed mining claims and to harmonize regulatory procedures. Among the nations involved are France, Britain, Belgium, and Japan.

Many of the nations that have focused their efforts exclusively on an international LOS approach have expressed opposition to an RSA that could be construed as a "minitreaty" intended to evolve into an alternative mining regime outside the LOS Convention.

We note that the United States was the only industrialized nation to vote against adoption of the LOS Treaty. As one of the few "pioneer" mining states — those which have already invested significant amounts of money in deep seabed mineral development — the U.S. is moving forward with implementation of the domestic Deep Seabed Hard Mineral Resources Act of 1980. Final regulations for issuance of exploration licenses under the Act were issued in October of 1981. License applications were accepted in early 1982 pursuant to those regulations.



Transfer at sea of nodule slurry from a mining ship to a transport ship. (From Deep Seabed Mining — *Final Programmatic Environmental Impact Statement, National Oceanic and Atmospheric Administration)*

While several applications have been submitted, there is the very real risk that U.S. failure to participate in the LOS Convention could result in the loss of this country's seabed mining industry. Among potential problems, the questionable legality of a unilateral regime could make it very difficult to get the enormous venture capital that is required. Several domestic companies have already taken steps to protect their long-term interests by registering in other industrialized nations.

Future Concerns

As the development of deep seabed mining moves forward, considerable attention must be given to the regulatory framework necessary to deal with the potential adverse impacts that mining could have on the marine environment. Given what little is known technically of both the short- and long-term impacts, considerable caution must be exercised. To date attention has been focused primarily on developing the technology to retrieve nodules from the ocean floor and to process them in a commercially viable way. A comprehensive environmental framework, including enforcement mechanisms, must be an integral feature of further development as we improve our understanding of the deep ocean, the water column, the ocean surface, and the near-shore regions of the marine environment.

Clifton Curtis is an attorney with the Center for Law and Social Policy, Washington, D.C. He has represented various American and European environmental organizations concerned with an environmentally sound Law of the Sea Convention, and has participated in the enactment and implementation of the U.S. Deep Seabed Hard Mineral Resources Act of 1980 on behalf of American environmental groups.

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Manganese Nodules: Unanswered Questions

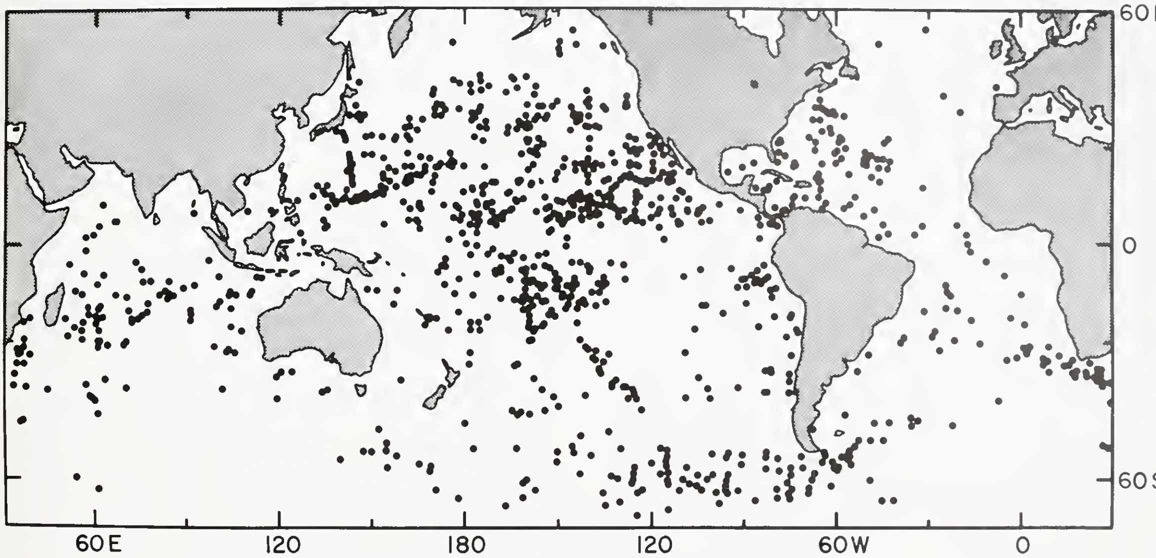

Figure 1. Locations at which oceanographic research vessels have collected deep-sea manganese nodules.

by G. Ross Heath

Manganese nodules cover much of the deep ocean seafloor (Figure 1). Their presence and their interesting geochemistry have been known for more than a century. Yet many questions about their formation remain unanswered. In particular, we still do not know why nodules begin to form at a specific location; why they are widely separated in some places but densely packed in others; how they are kept at the seafloor; and how the valuable elements of copper, nickel, manganese, and cobalt get into the nodules.

It is only fair to point out, however, that we also have learned a great deal about nodules during the last century. Many of the problems of a decade ago have been solved. For example, we know that the presence or absence of nodules is correlated with the rate of accumulation of the associated sediments. Where the deep-sea clays accumulate at more than about 7 millimeters per 1,000 years, nodules are absent. Thus, nodules mark the areas where there is no major source of sediments, or where bottom currents sweep the sediments away.

We also know that nodules grow very slowly. By analyzing nature's clocks, the naturally radioactive elements continually incorporated into growing nodules, we found that their growth rates range from about 1 to 200 millimeters every million years.

Such slow growth means that the typical nodules found on the seafloor have been growing there for a few hundred thousand to a few million years. This conclusion is supported by the relative abundance of nodules of different sizes (Figure 2). During such long periods, however, several tens of centimeters to several meters of sediment have been deposited at these same locations. Why are the nodules not buried in sediment?

We never have been able to observe the processes keeping the nodules moving upward. Indirect evidence, however, suggests that the benthic animals living in and on the seafloor are responsible. Deep-sea photographs show small animals cleaning the tops of nodules by eating newly arrived sediment. This behavior makes sense because freshly settled sediment is richer in organic matter and therefore more nutritious than sediment which has lain on the seafloor for some time.

We cannot photograph animals in the sediment, but man-made radioactive elements, such as plutonium (created during atmospheric nuclear tests) have been found in the sediment beneath a large nodule. This suggests that benthic animals moved the sediment from the seafloor to a depth of several centimeters and then under the bottom of the nodule, all within the last 20 years or so. We

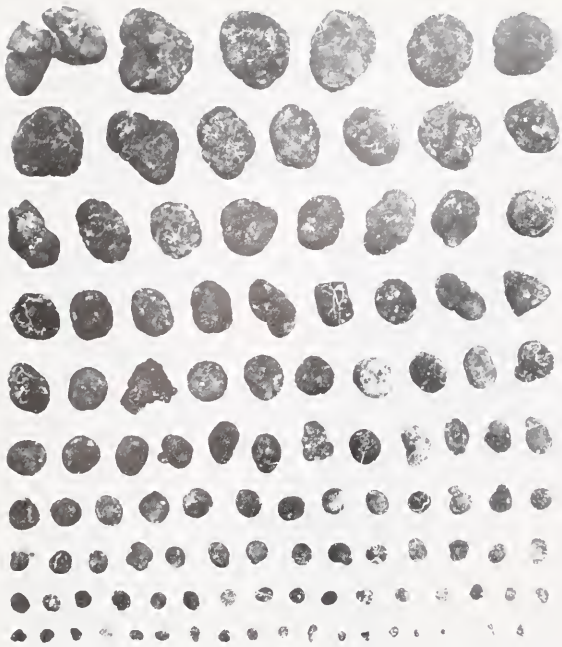

Figure 2. Typical collection of manganese nodules from a 50 x 50 centimeter sampler. The range of sizes (largest nodule is approximately 10 centimeters in diameter) is consistent with the theory of continuous formation, growth, and burial of nodules.

suspect that burrowing produces a slight lifting effect which, in combination with the "housecleaning" efforts of the small surface animals, keeps nodules moving upwards rapidly enough to avoid burial in the slow, steady rain of pelagic sediment.

How Nodules Form

Recent studies also show that both the chemical compositions and growth rates of nodules are closely related to the biological productivity of their overlying surface waters. Beneath the "marine deserts" — the unproductive waters of the great mid-latitude oceanic gyres — nodules are rich in iron and cobalt, metals we believe are extracted by the nodules from the bottom waters of the oceans. Such "authigenic" nodules grow very slowly (less than 5 millimeters per million years).

Beneath the margins of biologically productive areas (to the north and south of the equator in the Pacific, for example) the nodules grow more rapidly (5 to to 10 millimeters per million years) and are enriched with copper, nickel, and, to some extent, manganese. We believe that these metals are carried to the seafloor in the remains of microscopic plants and animals that died or were eaten at the surface and settled through the water column. At the seafloor, decomposition of the settling particles releases the metals, which are then transferred to the nodules by a process we do not yet understand, called "oxic diagenesis." Figure 3 shows the resulting distribution of copper-rich nodules in the Pacific.

Finally, beneath the most biologically productive areas (but only where the rain of microscopic shells does not increase the sedimentation rate to more than about 7 millimeters per 1,000 years), the nodules grow much more rapidly (10 to 200 millimeters per million years). These nodules are greatly enriched in manganese relative to other metals. In such areas, so much organic matter settles to the seafloor that its decomposition uses up the oxygen dissolved in the porewaters of the sediment. When this happens, manganese is reduced from its very insoluble tetravalent form (as found in manganese dioxide, for example) to the soluble divalent form, which can diffuse upward through the porewaters to the growing nodules. This process, called "suboxic diagenesis," supplies so much manganese to the nodules that the economically important elements — copper, nickel, and cobalt — are diluted to very low concentrations.

Figure 4 summarizes data for nodules from three Pacific areas of differing productivities. These results, from J. Dymond of Oregon State University, illustrate the transition from authigenic, through oxic diagenetic to suboxic diagenetic nodules. The nodules of greatest economic interest, which created so much turmoil at the Third United Nations Conference on the Law of the Sea (UNCLOS), are those richest in copper and nickel. Such nodules form at locations where oxic diagenesis is not quite overwhelmed by suboxic diagenesis.

Economic Concerns

How do recent scientific results bear on the economic potential of nodule mining and on the UNCLOS deliberations?

It is clear that economically attractive nodules will be found only in areas that border on biologically productive regions and that have very slow sedimentation rates. For mining to be practical, the mine site must have abundant nodules (more than 5 kilograms per square meter) which are relatively rich in copper and nickel. These criteria limit the number of prospective mine sites to somewhere between 10 and 60 (assuming 3 million tons per year are needed for a 20- to 25-year mining venture). Thus the resource is not nearly as large as was supposed 20 years ago. This information must be reassuring to land producers of copper and nickel, who would have to compete with the nodule miners, but it places added pressure on any international regime that is supposed to derive the maximum return from nodule mining for the benefit of less-developed countries.

The nodules richest in cobalt — of strategic interest to the United States — are found over a much wider area than those richest in copper and nickel. Unfortunately, only nodules on seamounts (submarine mountains) contain more than 1 percent cobalt. These would be difficult or impossible to mine economically. Deep-sea nodules rarely contain more than 0.7 percent cobalt. As a result, even at current prices, mining nodules purely for their cobalt makes little economic sense. The economically optimum mix of cobalt, copper, and nickel is most likely to lie in the areas of darkest shading on Figure 3.

Finally, it is clear from the recent scientific results on nodule growth rates that the resource

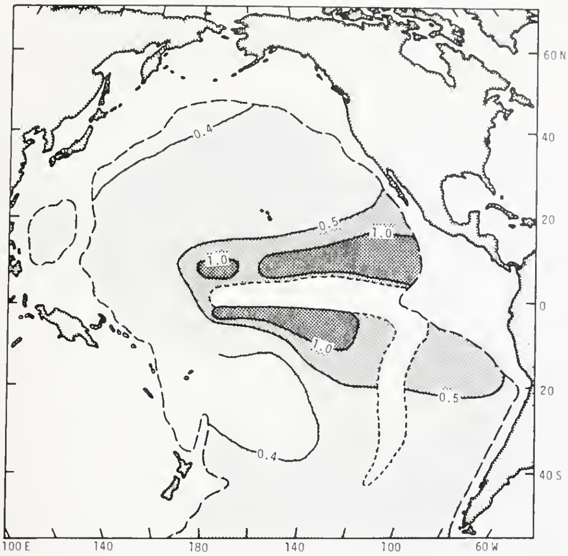

Figure 3. Regions of the Pacific Ocean where the nodules richest in copper are found. The values on the contours indicate the percent of copper by weight. Nodules containing more than the indicated percentage of copper lie within that contour. Nodules of lower grade are scattered through the richer deposits. Blank areas are nodule-free because of the deposition of sediment around the ocean margins and calcareous ooze along the equator and East Pacific Rise at rates of more than 7 millimeters per 1,000 years.

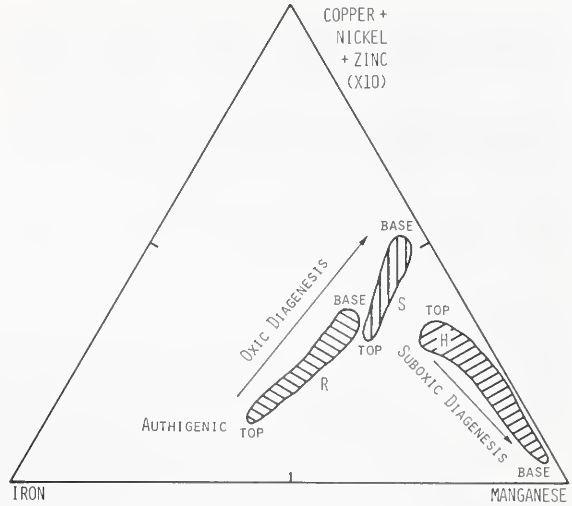

Figure 4. Compositions of Manganese Nodule Program (MANOP) nodules in terms of several important metals. Samples close to an apex of the triangle are richest in that metal. R,S, and H identify nodules from red clay (north of Hawaii), siliceous clay (southeast of Hawaii, where mining interest is greatest), and hemipelagic clay (west of Costa Rica), respectively. "Top" indicates nodule material in contact with seawater; "base" indicates nodule material buried in sediment. Biological productivity increases from R to H. The compositional trends show the transition from authigenic to oxic diagenetic to suboxic diagenetic nodules discussed in the text (Courtesy of J. Dymond).

cannot be considered renewable on a time scale of any interest to us or even to our great-grandchildren.

Environmental Concerns

In the economically attractive area of the Pacific, the seafloor is rather dynamic, with extensive natural erosion and redeposition of pelagic sediments. Thus we do not expect nodule mining to catastrophically affect the deep-sea benthos away from the mined areas. However, the possibility of less severe, but nevertheless significant effects on the more distant faunas as the result of exposure to low concentrations of sediment stirred up by miners must be considered, although it will be difficult to assess. In an attempt to address this issue, the United States proposes that deep-sea "Stable Reference Areas" be established for scientific study. A recent review of this concept

Nodules in Fresh Water

Polymetallic nodules are not just a marine phenomenon, but are plentiful in many lakes and swamps as well. Most lake nodules are plate-shaped, from an inch to a foot in diameter and less than an inch thick. In swamps, they are more likely to be round, often pea-shaped.

Usually high in iron (averaging 35 percent iron oxide and 7 percent manganese oxide by weight), these nodules were called "bog iron" by American colonists. After heating nodules with charcoal and hammering out impurities, blacksmiths fashioned nails, hinges, and other implements, a practice that was replaced gradually in the early 1800s by open pit mining and high-temperature smelting.

Nodules are abundant in shallow lakes with slow sedimentation rates, such as those in Scandinavia, where they provided iron for the Vikings. Lake nodules usually contain much less copper, cobalt, and nickel than ocean nodules, but they grow faster — sometimes more than a centimeter in diameter every 100 years. Some lakes in Sweden contain nodules with a copper content higher than in the deep sea because their shores have long been repositories for copper mine tailings.

In North America, dense coverages of nodules are found on the bottom of Lake Michigan's Green Bay, where iron-rich water upwelling from the stagnant depths meets water with a higher oxygen content. Some Nova Scotia and Wisconsin lakes contain nodules in which manganese is the dominant metal — an unusual occurrence in fresh water.

by a committee of the National Academy of Sciences, in which the author participated, suggested that two types of reference areas be created.

"Preservational" areas would be located so as to minimize the likelihood of disturbance by mining activities. Long-term research programs in such areas would help define the natural variability of deep-sea ecosystems across a small area over a time period of several years.

"Impact" areas would be located adjacent to mining areas. By applying the knowledge gained from research in "preservational" areas to "impact" sites, the likelihood of detecting effects of chronic low level exposure to mining debris will be greatly increased.

Still to be established are criteria that will determine when deleterious environmental effects are so severe that mining activities will have to be curtailed or stopped. Such criteria inevitably will be quite subjective and will generate a lot of heated discussion even in the marine biological community, not to mention in the mining industry.

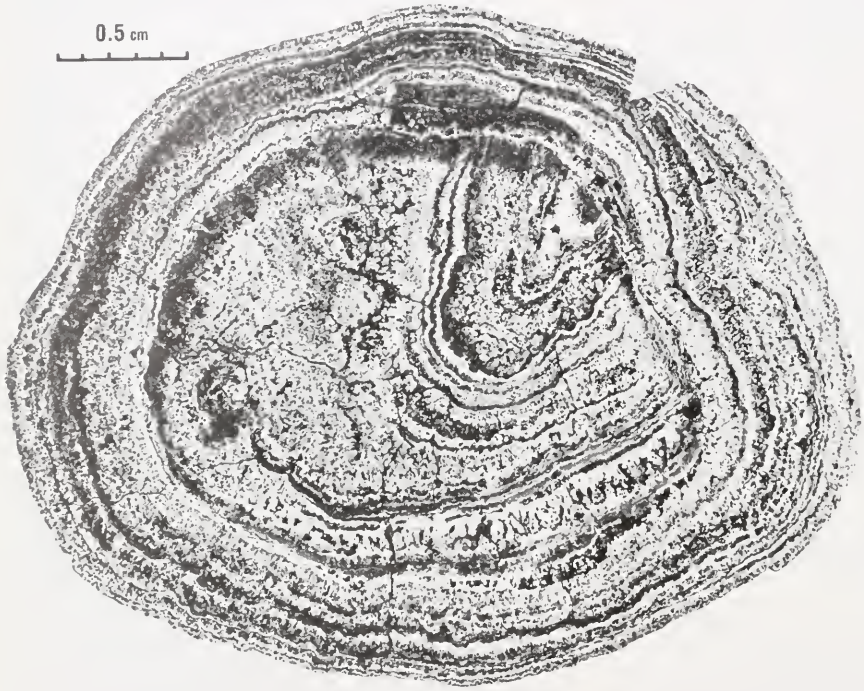

Figure 5. Polished interior of a nodule sawn in half. (Courtesy of R. K. Sorem and R. H. Fewkes)

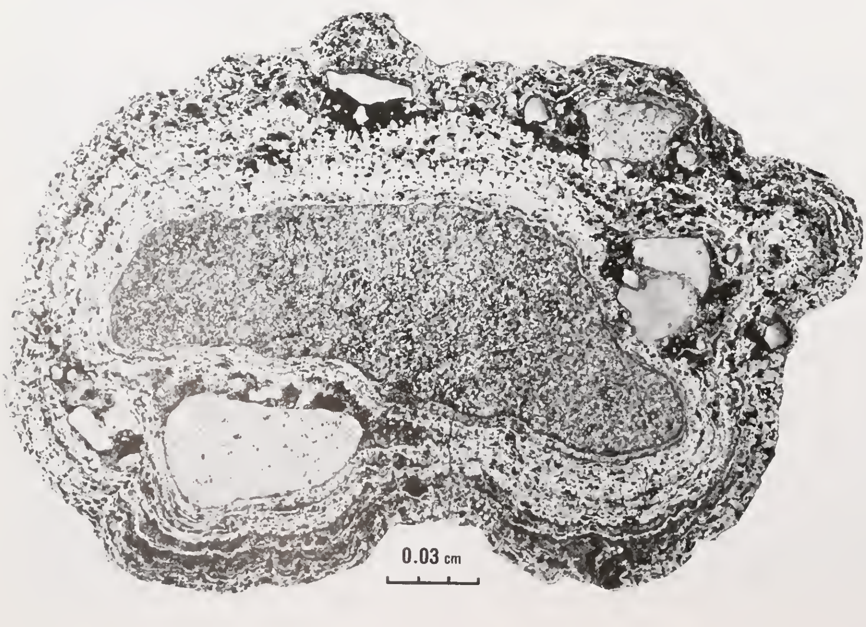

Figure 6. Polished interior of a fairly typical North Pacific nodule. The layering could be formed by changes in the conditions at the surface of the growing nodule, or by later chemical reactions within the nodule. (Courtesy of R. K. Sorem and R. H. Fewkes)

At the moment, the research required to establish or defend such criteria simply has not been done.

Future Research

Future studies of nodules will focus on regional patterns of nodule abundance and composition, and on detailed studies of single nodules to unravel the processes affecting their growth and composition.

Regional studies will attempt to determine how changes in average nodule properties over distances of tens to thousands of kilometers are related to other oceanographic factors, such as biological productivity, the nature and activity of benthic animals, bottom currents, composition, rate of accumulation and early diagenesis of sediments, composition of bottom waters, and bottom topography.

The detailed examinations of nodules will try to define the chemical environment in contact with various parts of nodules; the reactions between pore solutions, sedimentary particles, and nodules; the role of bacteria and benthic organisms in nodule growth; and the histories of growth and internal recrystallization of specific nodules (Figures 5 and 6). In many cases, these detailed studies will require careful experiments at the seafloor. One instrument that has been designed to carry out such experiments is the Manganese Nodule Program (MANOP) Bottom Lander (Figure 7). This device "captures" a piece of seafloor and a few nodules in a special chamber. The sample is then treated with solutions containing, for example, such things as antibiotics and dissolved metals, to determine the role of bacteria in concentrating metals in the nodules. At the end of the test, sediment, nodules, and overlying seawater are brought to the surface for detailed laboratory studies. Such experiments are difficult and time consuming, but they hold great promise for increasing our understanding of these enigmatic objects.

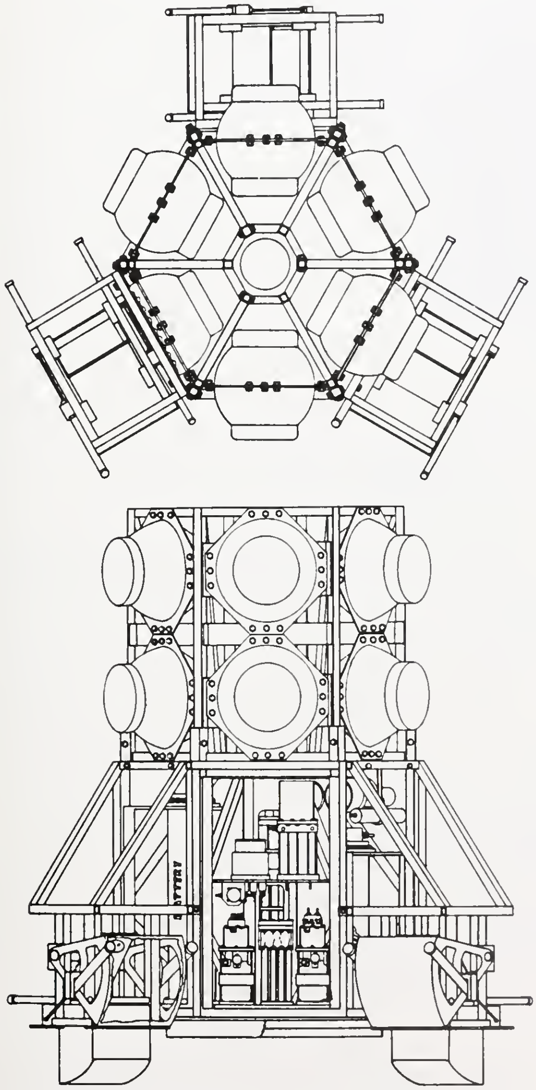

Figure 7. The Manganese Nodule Program (MANOP) Bottom Lander, top view (above) and side view (below). This device is lowered to the seafloor, where the chambers isolate small areas of sediment and nodules. Computer-controlled experiments, involving the addition to or removal of water from these chambers, can be preprogramed or modified by acoustic commands from the mother ship above. At the end of an experiment, the lander seals off the sediment, nodules, and water in each chamber, pushes itself off the bottom, and floats to the surface to be hoisted on board the mother ship.

G. Ross Heath is Dean of the School of Oceanography at Oregon State University, Corvallis, where he is also a Professor of Geological Oceanography. He has been a member of the Manganese Nodule Program (MANOP), supported by the National Science Foundation, since 1976.

Metal Sulfide
on the Juan

by Randolph A. Koski,
William R. Normark,
Janet L. Morton,
and John R. Delaney

Dark gray sulfide fragment from the Juan de Fuca Ridge.

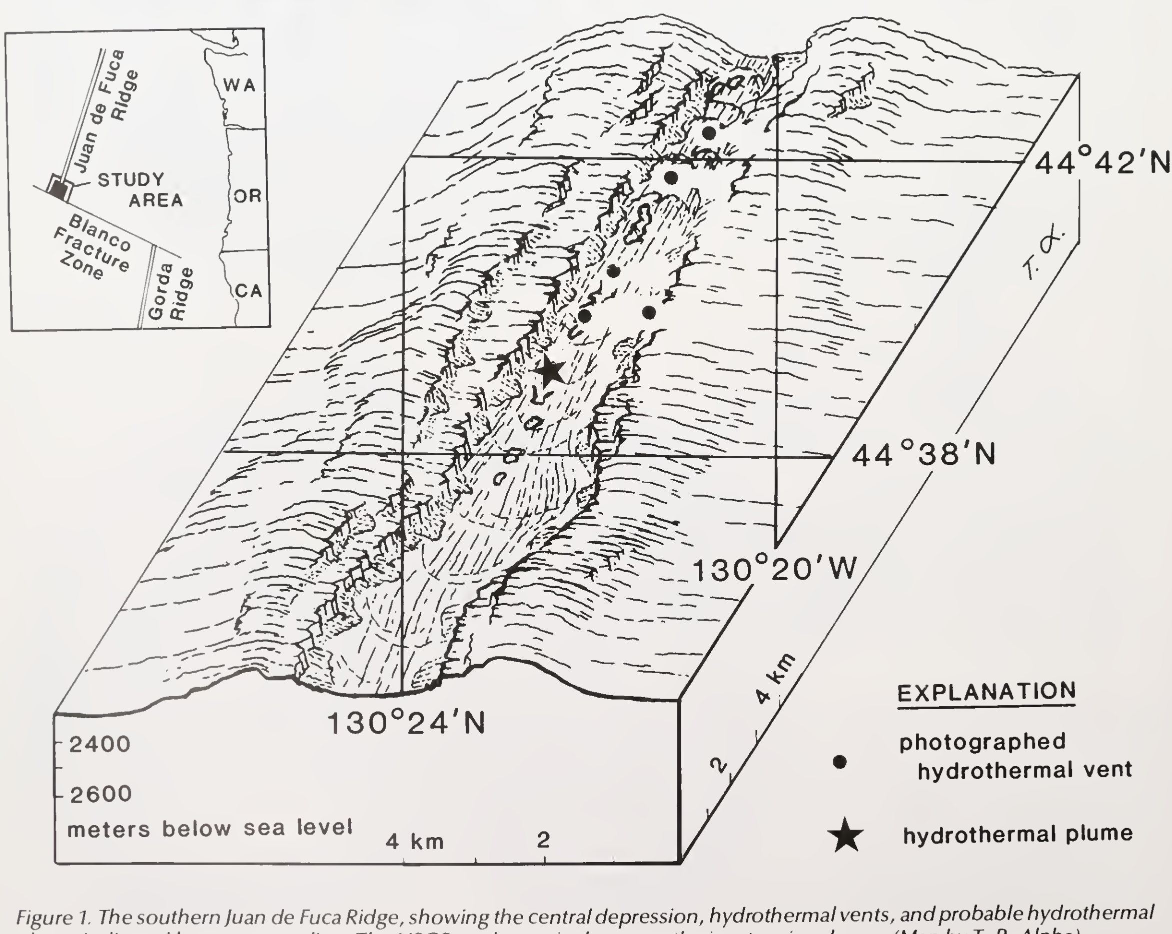

Figure 1. The southern Juan de Fuca Ridge, showing the central depression, hydrothermal vents, and probable hydrothermal plume indicated by water sampling. The USGS study area is shown on the inset regional map. (Map by T. R. Alpha)

Deposits
de Fuca Ridge

Oceanic ridges are submarine mountain ranges formed at the edges of oceanic plates by the process of sea-floor spreading. Since 1974, active hot springs and metal-rich sulfide deposits have been detected and sampled at several localities where the rate of spreading at the ridge crest is medium to fast, such as at the East Pacific Rise, the Galápagos Rift, and the Juan de Fuca Ridge. The mineral deposits are forming where heated seawater (carrying large amounts of dissolved metals and sulfur) gushes from the seafloor, frequently with enough force to produce particle-filled clouds, or "black smokers," above the vents. The metals — mainly zinc, iron, copper, lead, silver, and cadmium — combine with sulfur, precipitating from solution as metal sulfides. These minerals then accumulate in platforms and mounds that are commonly topped by towering chimneys composed of sulfide and sulfate compounds. Under the sulfide deposits, in the axis of the spreading center, are newly formed volcanic rocks or sediments.

The Juan de Fuca Ridge is a 500-kilometer-long, medium-rate spreading center that separates the Juan de Fuca and Pacific oceanic plates off the coast of Oregon and Washington (Figure 1). The southern end of the ridge is terminated by the Blanco Fracture Zone, a transform fault that displaces the southern extension of the ridge approximately 350 kilometers to the east, where it is known as the Gorda Ridge. In September 1981, a research team composed of scientists from the U.S. Geological Survey (USGS) and the University of Washington located hydrothermal vents and dredged samples of sulfide mineral deposits from a water depth of about 2,200 meters at the southern end of the Juan de Fuca Ridge, about 500 kilometers off the Oregon coast. This segment of the ridge was chosen for the survey because it is geologically uncomplicated and has a relatively fast spreading rate (the plates are separating by approximately 6 centimeters a year) similar to that at other ridges known to have hydrothermal vents and sulfide deposits. Furthermore, a previous sea-floor survey by the University of Washington revealed evidence of recent volcanic activity and the presence of small, bottom-dwelling organisms called benthic siphonophores, known to inhabit other hot spring sites.

During the 1981 cruise to the southern Juan de Fuca Ridge, normal navigational methods for the USGS research vessel *S. P. Lee* were augmented by an acoustic transponder array placed along the axial valley. This additional instrumentation assured accurate fixes on ship location and the deep tow apparatus and also pinpointed ship positions for bathymetric mapping during each crossing of the ridge.

The vent sites were discovered by photography accomplished by a camera mounted on a sled and towed behind the ship. The camera system, built at the University of Washington, uses two 35mm cameras housed in a tube steel cage designed to be towed about 5 meters above the seafloor. The cameras operate individually and consecutively; approximately 7,300 black-and-white and 900 color photographs were taken during 12 passes across the study area lasting 4½ hours each.

Samples of volcanic rock and hydrothermal deposits were recovered with a circular-frame, chain-bag dredge equipped with a relay transponder and pinger to fix its position relative to the ship and the seafloor. At dredge stations over vent sites, the dredge was towed near the seafloor to the vent site where it was quickly dropped to the bottom and dragged across the vent area before being pulled clear of the bottom. The dredge recovered fragments of fresh, glassy basalt at 11 stations. The 12th station yielded several hundred kilograms of basalt and 12 kilograms of massive metal sulfide.

Geologic Setting

The southern Juan de Fuca Ridge has a simple profile (Figure 1): a smooth, flat, 1-kilometer-wide axial valley enclosed by steep, symmetrical valley walls and ridges. The relief between ridge top and valley floor is 80 to 100 meters. The valley walls and a low terrace about 30 meters above the valley floor are related to steep normal faults formed by the perpetual separating of the two adjacent plates.

Bottom photographs and pinger records show that the planar valley floor has a narrow and sharply defined medial depression that is nearly continuous in the northern part of the study area (Figure 1). This topographic feature is 50 to 200 meters in width, has a maximum depth of 25 meters, and may have formed by collapse of a lava lake or by faulting.

Bottom photographs also show that the flat axial valley floor is made up largely of thin, flat sheet flows of basaltic lava. Sediment cover is minimal in the current-swept trough. The sheet flows have a ropy surface texture known as pahoehoe lava. Dredged samples of fresh basalt have unaltered glassy surfaces, indicating that the volcanic rocks are less than a few hundred years old. Alteration is limited to coatings of iron and manganese oxides on exposed surfaces and fractures. Pillowed lavas are not abundant on the valley floor, but are present in the valley walls. Away from the central depression,

collapse pits and open cracks or fissures in the valley floor are uncommon. This contrasts with the axial zone of the East Pacific Rise at 21 degrees North and the Galápagos Rift, where complex fault-block terrains and pillowed lavas are typical.

Hydrothermal Vents

Five hydrothermal vent sites were observed in bottom photographs taken in the axial valley in the northern half of the study area (Figure 1); four are within or along the edges of the axial depression and the fifth occurs at the base of the eastern valley wall. Visible photographic evidence of a vent site consists of multicolored crusts, ledges, and mounds of hydrothermal material and concentrations of bottom-dwelling organisms, such as clams, worms, and crabs. An additional hydrothermal discharge was indicated by high amounts of dissolved manganese in water samples taken at a location near the center of the study area.

The hydrothermal material is easily identified in black-and-white photographs (Figure 2). It consists, in part, of a light-colored, easily dispersed precipitate that forms a loose cover over volcanic rock and older hydrothermal deposits. Low-lying ledges and small mounds of darker, stony-looking sulfide make up the bulk of the hydrothermal deposits. Chimney structures constructed of sulfides are not abundant, and no black smokers were observed. However, in a few photographs (for example, Figure 2) the bottom water has a cloudy appearance suggesting that the camera was positioned near an active hot spring.

Figure 3. Tube worms attached to depressions or cracks in hydrothermal deposits. An unidentified fauna is concentrated in low areas around small, dark sulfide mounds. The scale represents approximately 1 meter.

Figure 2. Hydrothermal vent field, showing shallow ledges of light and dark hydrothermal deposits. The light material is a loose surficial precipitate; the dark material is a thicker deposit of stony zinc-rich metal sulfide. The cloudy appearance of the water at left may indicate an active hot spring. The scale represents approximately 1 meter.

Within the vent sites, small-diameter tube worms occur in clusters or as solitary individuals that extend upward in the water column from depressions and cracks in the hydrothermal deposits (Figure 3). An abundant, but unidentified fauna, seen in Figure 3, is commonly concentrated in low areas around small sulfide mounds. Small clams and scattered clam-shell debris are also present in many photographs.

The ledges and mounds of light and dark hydrothermal precipitates with abundant tall tube worms are probably close to the actual vents of hydrothermal discharge. Clam shells, crabs, and thin coatings of the light-colored precipitate are common features near the periphery of the vent areas. The tube worms, clams, and other organisms of the Juan de Fuca study area appear to represent less robust life forms than those associated with hot springs on the East Pacific Rise.

Composition and Formation of Sulfide Deposits

The sulfide samples recovered from the southern Juan de Fuca Ridge are porous crystalline aggregates of zinc, iron, copper, and lead sulfide. Two types were recovered: angular slabs of somewhat friable, granular, dark-gray zinc sulfide with an upper crust and interlayers of iron sulfide (Figure 4A) and

rounded fragments of hard, spongy-looking, light-gray zinc sulfide (Figure 4B). The dark-gray sulfide samples consist largely of the minerals sphalerite, wurtzite, and pyrite, with minor marcasite, galena, and chalcopyrite. Minor nonsulfide minerals include anhydrite, gypsum, barite, and amorphous silica. These minerals generally occur as thin films or clusters of elongate crystals in cavities.

Sphalerite is the most abundant sulfide mineral and has two forms. It is present as globular or "colloform" crystals with an internal construction of delicate growth bands, and as angular overgrowths that project into open space (Figure 5A). Wurtzite, in contrast, forms shiny six-sided crystals with broad growth bands (Figure 5B), and is abundant in cavities. Sphalerite and wurtzite are also abundant in the sulfide mounds and chimneys at the East Pacific Rise vent site.

In dark-gray sulfide samples, the iron-sulfide minerals pyrite and marcasite occur as lenses, clusters, and discontinuous layers of globular crystals enclosed by zinc sulfide. Galena and chalcopyrite form small angular inclusions in zinc-sulfide minerals. The iron-sulfide crusts have a thin orange-red film of oxidation, suggesting that these surfaces were in contact with oxygen-rich seawater on the seafloor. The opposite surfaces of dark-gray sulfide slabs are porous and free of alteration; these surfaces were in contact with hot, mineralizing fluids exiting from the seafloor.

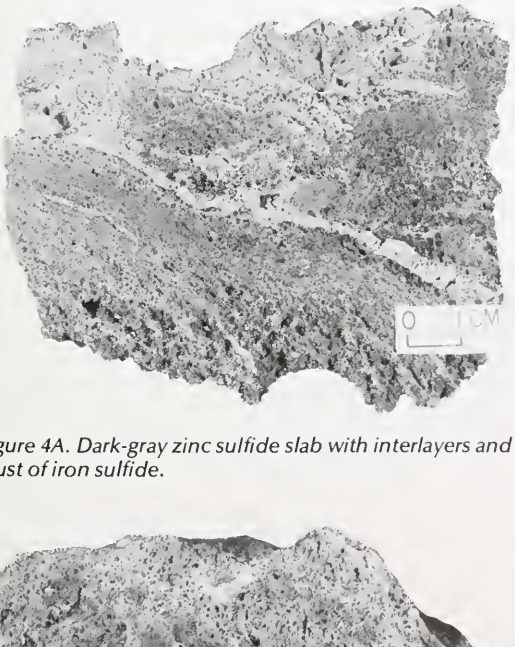

Figure 4A. Dark-gray zinc sulfide slab with interlayers and crust of iron sulfide.

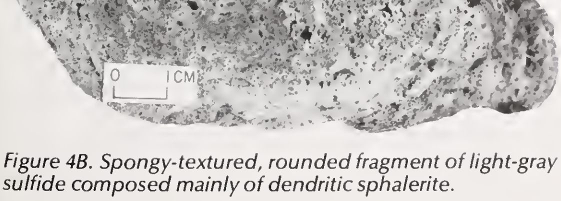

Figure 4B. Spongy-textured, rounded fragment of light-gray sulfide composed mainly of dendritic sphalerite.

Several samples of dark-gray zinc sulfide contain numerous closely-spaced, 1-centimeter-wide tubes (see back cover) left behind by burrowing organisms, probably the larger worm-like animals observed in bottom photographs. Although no organic material remains, the tube walls have a consistent zonation: outer and inner walls of pyrite enclose a flaky layer of silica. The tubes may be empty or partly to completely filled with zinc and iron sulfides. Sulfide deposits within tubes suggest that the tubes were channels for mineralizing solutions after abandonment by organisms.

The light-gray sulfide samples consist of pale-gray to colorless sphalerite in a spongy aggregate of branching growth forms. Abundant irregular cavities result in a high (30 to 35 percent) porosity. The cavities appear to result from the mineral growth pattern rather than the presence of organisms. A few scattered grains of pyrite are embedded in the sphalerite; copper- and lead-sulfide minerals are absent. Unlike the dark-gray sulfide, where cavities contain clusters of wurtzite crystals, the cavities in light-gray sulfide samples contain spherules or thin coatings of silica, scattered prisms of barite, and rare patches of iron oxide.

Microscopic studies reveal that the dendritic sphalerite is locally colloform with delicate internal growth banding (Figure 5C). The color variation in the bands is the result of variations in the ratio of iron to zinc and the amount of intergrown silica in the zinc sulfide. The light color of this sphalerite indicates a lower iron content than in the sphalerite and wurtzite from the dark-gray sulfide samples.

The bulk chemical compositions of dark- and light-gray sulfide samples are shown in Table 1. Both types of sulfide are rich in zinc, silver, and cadmium; on land these deposits would be considered to have ore-grade concentrations of these metals. Copper concentrations of both dark-gray and light-gray sulfides are lower, and the lead concentration of dark-gray sulfide is higher than the amounts of these elements in sulfide deposits from the East Pacific Rise and the Galápagos Rift. The zinc-rich sulfide samples from the Juan de Fuca Ridge may have been recovered from the lower-temperature top or edge of the massive sulfide deposit; higher-temperature, copper-rich sulfide may be present at the base of the massive sulfide deposit, at higher-temperature vents, or in fractures within the underlying volcanic rock.

The presence of hydrothermal deposits on the Juan de Fuca Ridge results from the large-scale circulation of seawater through the oceanic crust along the tectonically active axis of spreading (Figure 6). The movement of fluid within the circulation cell is related to a nearby heat source, presumably a body of basaltic magma at a shallow level (1 to 2 kilometers) beneath the ridge. This magma also supplies the lava extruded as sheet flows on the axial valley floor. The fluid circulation begins on the flanks of the ridge, where normal oxidizing seawater penetrates into the cooling basaltic oceanic crust. As the fluid becomes heated and chemically interacts with the basaltic

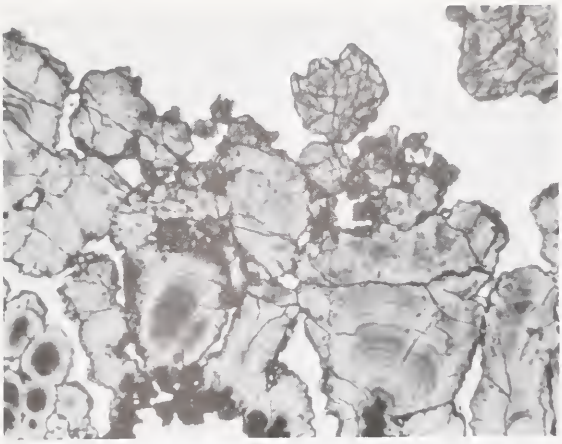

Figure 5A. Microscopic view of delicately-banded colloform sphalerite overgrown by angular crystalline sphalerite in dark-gray sulfide sample. Field of view is approximately 1 millimeter across.

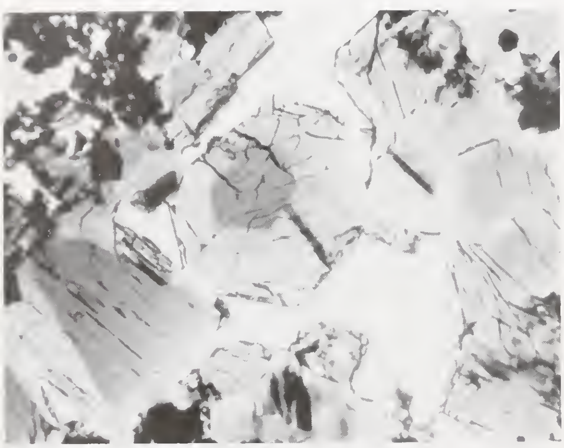

Figure 5B. Microscopic view of broadly zoned hexagonal wurtzite crystals in dark-gray sulfide sample. Field of view is approximately 0.5 millimeter across.

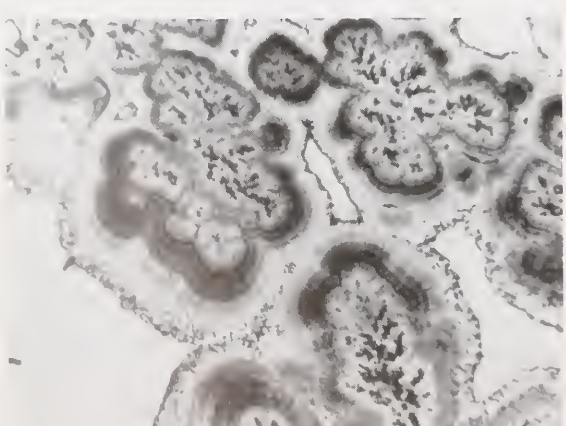

Figure 5C. Microscopic view showing low-iron colloform sphalerite in light-gray sulfide sample. Field of view is approximately 1 millimeter across.

Table 1. Results of bulk chemical analysis for two samples (by atomic absorption spectroscopy).

Element	Sample 1	Sample 2
Zinc (percent of weight)	54.0	59.2
Iron (percent of weight)	8.0	1.8
Copper (percent of weight)	0.32	0.07
Lead (percent of weight)	0.25	0.06
Silver (parts per million)	290	230
Cadmium (parts per million)	490	1,060

Sample 1: Dark-gray massive zinc sulfide with minor pyrite.
Sample 2: Light-gray spongy zinc sulfide.

wallrock, it evolves into a reducing and somewhat acidic solvent capable of extracting and transporting sulfur, iron, manganese, and other metals. Near the ridge axis, the high-temperature, metal-rich fluid is quite buoyant and rises along permeable zones, probably normal faults and rock fractures that crosscut the volcanic rocks of the axial valley floor. Metal sulfides may be precipitated along channelways under the seafloor as the ascending fluid begins to cool, but the vigorous flow is still hot when it reaches the seafloor. Here the spewing liquid mixes with cold seawater and the sulfides precipitate to form massive deposits. Further mixing of the hydrothermal solutions with seawater produces accumulations of iron and manganese oxide on basaltic surfaces surrounding the sulfide deposits.

Implications

The resource potential of hydrothermal sulfide deposits on the Juan de Fuca Ridge and other spreading centers is uncertain because of short- and long-term economic, political, and technological questions. Even more fundamental, perhaps, is the need for more information regarding the distribution, occurrence, and composition of deposits elsewhere on the oceanic ridge system.

At least five vent sites were observed in the northern half of the 12-kilometer-long USGS study area of the Juan de Fuca Ridge during the 1981 cruise. The sulfide deposits there appear to form shallow ledges less than 1 meter high, with occasional mounds of somewhat greater thickness. The width of the deposits traversed is 25 to 50 meters, but their dimension parallel to the valley is uncertain. However, their presence in all traverses in the northern part of the area suggests a nearly continuous distribution of deposits along the linear depression. These rough dimensions and the composition of the samples recovered imply that approximately 100,000 cubic meters, or 250,000 metric tons, of zinc- and silver-rich sulfide may lie within the study area. Because of the similarity in spreading rate and ridge morphology, it is reasonable to believe that additional deposits are located along the segment of ridge axis north of the study area.

Metal sulfide deposits along oceanic ridges may be analogous to massive sulfide deposits found in ophiolites, certain complexes on land. Ophiolites are layered sequences of mafic and ultramafic rocks that have lithological, structural, and geophysical characteristics similar to modern-day oceanic crust

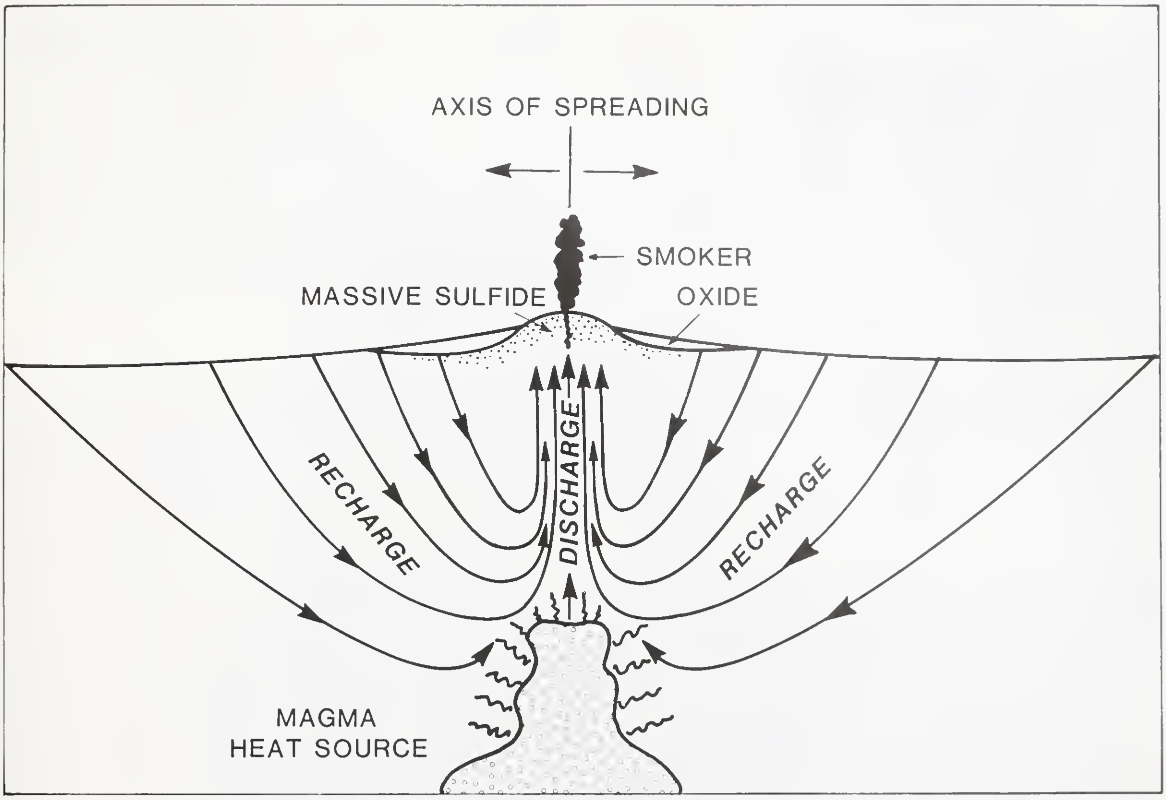

Figure 6. Model showing circulation of seawater through oceanic crust at a spreading center, and deposition of massive sulfide and oxide deposits on the seafloor. The circulation is driven by a heat source at depth, presumably a body of magma below the axis of spreading.

(see *Oceanus*, Vol. 22, No. 3, p. 23). They are thought to be fragments of ancient oceanic crust and upper mantle, formed during sea-floor spreading and subsequently uplifted onto and incorporated into the margins of continental land masses.

The upper parts of ophiolite sequences, especially the pillow lavas, host massive iron-copper-zinc sulfide deposits. These are mined for copper, gold, silver, iron, and sulfur in Cyprus, Turkey, Oman, the United States, and many other countries. The deposits range from a few thousand to 20 million tons of ore, containing 0.5 to 10 percent copper, 0.5 to 3 percent zinc, and a few ounces of gold and silver per ton. Ore-grade concentrations of cobalt also may be present. The sulfide mineral assemblage is characteristically simple: abundant pyrite, with minor chalcopyrite and sphalerite.

Massive sulfide deposits in ophiolites may represent hydrothermal mineralization on the seafloor at ancient oceanic spreading centers. The massive orebodies are commonly underlain by a network of sulfide veins, referred to as stockwork mineralization, that may extend to depths of 1 kilometer or more. These stockwork zones are thought to represent mineralization in underlying hydrothermal feeder systems.

Geological and geophysical investigations of active hydrothermal vents and sulfide deposits on modern spreading centers such as the Juan de Fuca Ridge will provide valuable information on the origin, occurrence, and distribution of mineral deposits in ophiolites. For example, the spacing and distribution of sulfide deposits on ocean ridges appear to be related to deep-seated normal faults that form during the spreading process. This association already has been recognized at mining

Pillow lava ophiolite sequences like this one in Alaska are mined for copper, gold, silver, iron, and sulfur. Ophiolites are thought to be fragments of ancient oceanic crust formed during sea-floor spreading.

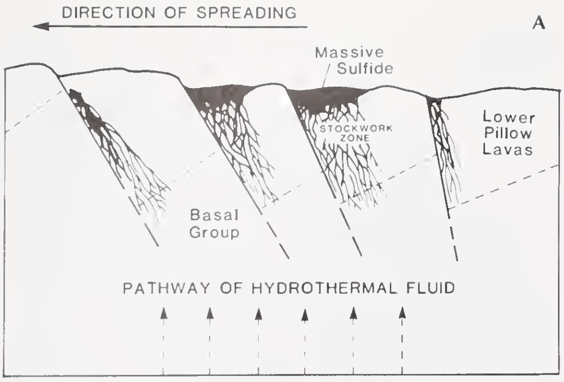

Figure 7. A: The relationship (simplified) of massive sulfide deposits in Cyprus ophiolite to faults created at an ancient spreading center (Adapted from N. G. Adamides, 1980). B: Mining a Cyprus deposit. The ore is the black material in the bottom of the pit. (Photo by R. Koski)

districts in the Troodos Ophiolite Complex in Cyprus (Figure 7), and should be applicable during mineral exploration programs in other ophiolite terrains.

The discovery of hot springs presently depositing metal sulfides on volcanically and tectonically active segments of seafloor presents a unique opportunity to apply the Uniformitarian Principle of Geology — "the present is the key to the past." Continued research on the mid-ocean ridge system will stimulate and improve our concepts in such diverse fields as volcanology, evolutionary biology, ore genesis, mineral exploration, and deep-seabed mining.

Randolph A. Koski is an economic geologist in the Office of Marine Geology, U.S. Geological Survey, Menlo Park, California. William R. Normark is a marine geologist in the same office. Janet L. Morton is a Ph.D. candidate at Stanford University, and John R. Delaney is an Assistant Professor of Oceanography at the University of Washington.

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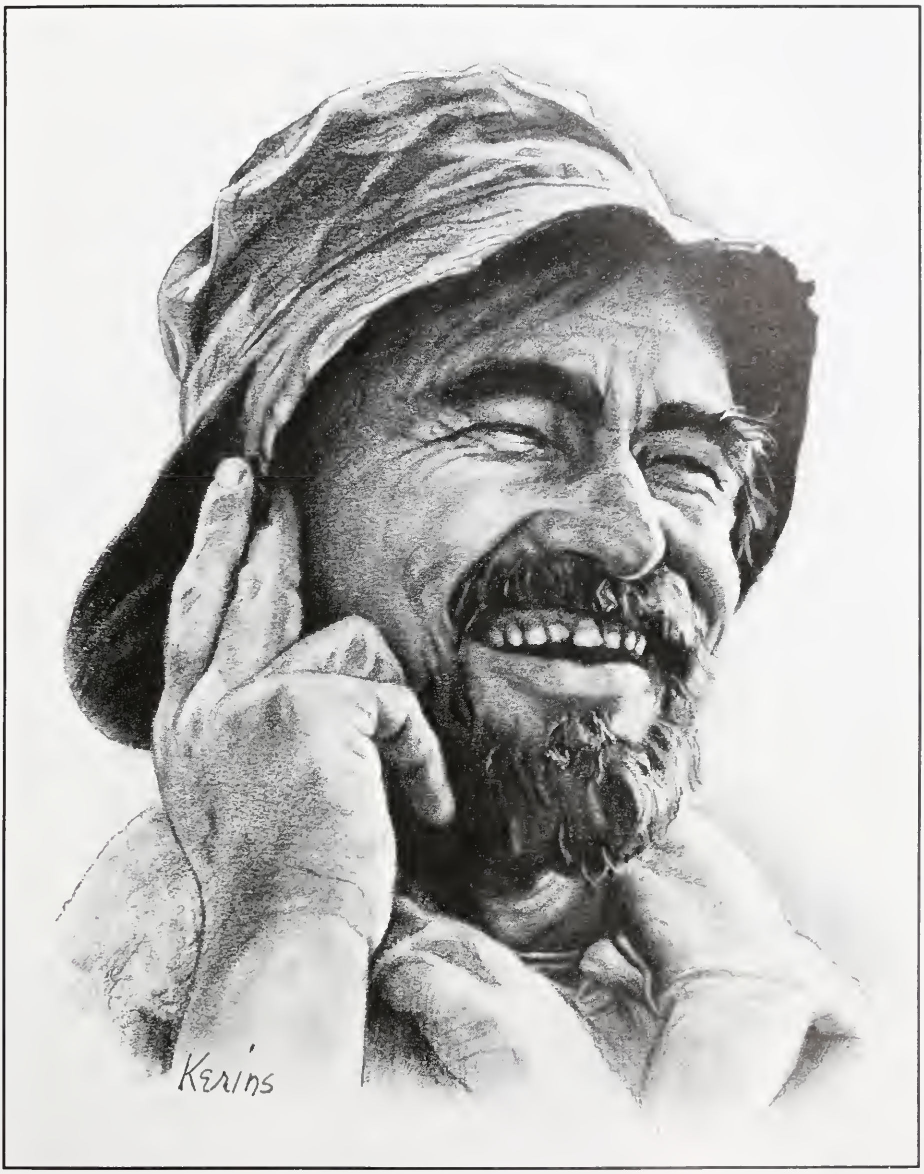
profile



John Moline Teal—*Marsh Man*

by William H. MacLeish

The boats were small and difficult to work in. The alternatives, for the curious young marine scientist, were the beach and the marsh. There was a lot more marsh than beach, and that is how John Moline Teal says he became a marsh man. At 52, Teal is a leading expert on marine wetlands.

He appears shy, and is. Yet his look is direct, even accipitral, and the wooden clogs he often wears, even in winter, mark him loudly in any shuffling crowd. He is chairman of the big and branching Biology Department at the Woods Hole Oceanographic Institution. "I can call myself an ecologist," he says. "I can call myself an oceanographer." He

laughs a little at himself, this Nebraskan born and raised in Omaha. "In certain audiences, I can call myself a chemist." He also could call himself a scientist in the ring; his style of unruffled pugnacity lends itself to the long and often nasty skirmishes waiting for the researcher who gets into public policy.

Teal sees drilling for oil on Georges Bank as a "marvelous opportunity for doing a large-scale scientific experiment."

"Along the eastern coast of North America, from the North where ice packs grate upon the shore, to the tropical mangrove swamps tenaciously holding the land together with a tangle of roots, lies a green ribbon of soft, salty, wet, low-lying land, the salt marshes." So begins *Life and Death of the Salt Marsh,* a well-received book written in the late 1960s by Teal and his first wife Mildred. The Teals first felt the draw of that green ribbon when John, fresh from eight years at Harvard (B.A., M.A., Ph.D.), began his professional research career at the University of Georgia's marine laboratory on Sapelo Island. Then followed a stay in Nova Scotia, where Teal was the first appointee in Daihousie University's new Institute of Oceanography. After two years, he moved to Woods Hole. "I'm not altogether certain why I came," he says. "I do remember that one of my friends up there warned me that if I stayed I could remain a big frog in a small puddle, while if I came down here I would get lost in a big puddle."

Teal does not act lost. His work in the Great Sippewissett and other lovely marshes gentling the shorelines of Cape Cod has put him somewhere near the center of a web of wetland research projects conducted by colleagues and former students. One of the earliest, a description of which ran in a 1972 issue of *Oceanus* under the decidedly unscientific title of "The Living Filter," involved the use of sterilized sewage sludge to fertilize plots of marsh grass. "Salt marshes can remove nitrogen very effectively from polluted waters that pass through them," wrote Teal and his co-author, Ivan Valiela, a biologist at the Marine Biological Laboratory in Woods Hole. "They act as tertiary sewage treatment systems for our coastal waters." Environmentalists of the more fundamentalist persuasion were taken aback, but Teal — who admits he was overly optimistic about the purifying powers of marshes — still believes in the concept.

Teal's present interests include decomposition in marshes: sulfate reduction in anoxic muds; factors controlling the rates of decomposition; fungal versus bacterial decomposition; the role of animals in the decomposition process; the contributions of nitrogen compounds resulting from decomposition to the energy turnover of the marsh; water movement through peat; the pulse-like nature of nutrient-rich runoff from the marsh; heavy metal cycling. And birds — Teal has been interested in sea and coastal birds since a friend introduced him to the long-billed marsh wren back on Sapelo. And oil.

The spill in 1969 of Number 2 oil around Wild Harbor, a few miles from Woods Hole, developed into one of the longest studies of the effects of petroleum on the marine environment. Teal was drawn to it because the fuel oil had invaded a marsh. Gradually, he began thinking of what oil might or might not do in the open ocean. In the mid-1970s, when the federal government decided to offer oil- and gas-exploration leases on Georges Bank, an unusually rich fishing ground off Cape Cod, Teal found what he calls his hobbyhorse.

"I see this thing," he told me a couple of years ago, "as a marvelous opportunity for doing a large-scale scientific experiment on Georges Bank. And that is to drill for oil. Drilling is going to do certain things. It is going to modify the environment in certain places. It is going to do it on a big enough scale so you can hope to measure the consequences." An experiment for the long term, replete with controls against which any significant changes could be measured: "That," said Teal, "is what I'm pushing for."

Teal has never really mounted his hobbyhorse himself; he has been too busy, he says, with other things. But he did push for the idea, sometimes angering colleagues, who thought he was not only talking about the giant experiment, but telling them how it should be run. Teal joined an ad hoc group of oil men, fishermen, environmental lawyers, and academic scientists. After several hours of ritualistic verbal combat, the participants discovered that in at least one area they were saying the same thing: Georges Bank did present a rare opportunity to discover what oil did to fishes and their food. Together, they worked out ideas for research programs and sent them to Washington, where an interagency task force was putting together a plan to monitor drilling and production on the Bank.

"I am personally convinced that it is always better to act on the basis of a little knowledge rather than on none."

Teal feels that there is no convincing evidence yet that exploratory drilling on Georges Bank will produce more than local effects. He believes studies should continue on drilling muds and other possible pollutants. But in his opinion, "the drilling phase studies are really going to be useful if they serve as a background for subsequent studies during production

phases. In the scientific sense, I hope we find oil out there, because that will make the study worthwhile." To ensure results, he thinks it is necessary to "monitor the monitoring effort and — assuming good science gets done and produces useful results — monitor the way in which the results get transformed into policy."

The man is eclectic in his consulting. He is well known and well respected by offshore leasing experts at the Department of the Interior, on whose scientific advisory group he serves. He also is a board member of the Conservation Law Foundation, which was the most effective combatant in court battles that postponed Georges Bank leasing until fisheries were better protected. Locally, he has advised both a conservation commission and a real estate developer.

More than ever, science is in the pressure cooker of policy and politics. Teal does not seem to mind the heat in the least. "I am personally convinced that it is always better to act on the basis of a little knowledge rather than on none," he says, swinging around from the window of his tiny cubicle and fixing me with his raptor's eye. "I think science can contribute a lot to an understanding of the consequences of certain actions. The difficulty lies in making people understand the limitations on that contribution. For one thing, scientists are people with opinions; they frequently fail to make it clear where their expertise stops and their opinion, their extrapolations from expertise, begins. I do it. We all do it."

Teal knows and sympathizes with prominent scientists who have either taken punishment and retired from the political ring or have refused to enter it at all. "It's a very tricky business. It's easy to get the feeling that the thing is too difficult; that being tripped up is inevitable; that you'll say something wrong and have somebody write — as someone did about me recently — 'I can't see how any responsible scientist could have said that.' "

"On the other hand," Teal says, "pulling out obviously doesn't help solutions to public policy questions that are based on good scientific information. If you leave it to the politician to make the decision in the lack of science, he will. He must. And then, it seems to me, the scientist has no one but himself to blame. You don't really have much of an excuse for complaining about what is happening in society if you don't contribute."

"Biologists traditionally have been less effective than others in putting together big projects and getting behind them and pushing."

Teal took on the chairmanship of his department this spring. "They wanted somebody who knows how the grant-getting and other systems work and how to hold up Biology's end in relation to the other departments. I wasn't the only candidate, obviously, but the others had better reasons for not doing it."

Holding up Biology's end is no simple task. Physical Oceanography at the Institution is in a leadership position internationally. Geology and Geophysics are spurred on by the current push for offshore minerals development. "Now, I clearly don't think that the biologists are of lower quality than scientists in the other departments," Teal says, grinning through his beard. "But I do think we have a great deal more competition. There are biological labs all around the country with good people in them. Also, biologists traditionally have been less effective than others in putting together big projects and getting behind them and pushing. Physicists seem to have done better at that, and then chemists and geologists. Biologists are the worst. Partly, I think that has to do with the great diversity in the field. We could divide the Biology Department into four or five departments which would be equivalent to or even broader in the extent of their discipline than, say, the Physical Oceanography Department. I suppose if you wrote that down somewhere and a physical oceanographer here read it, he wouldn't agree, but that's my opinion."

Teal tried his hand at classroom teaching but says he didn't take to it much. Clearly, he prefers smaller groups, where he can pounce on the imprecise, advocate the unpopular, and generally stir up the proceedings. Students tend to like him, says a colleague, "because he knows a lot and is generous with what he knows; but he's so busy he's sometimes hard to find." One former student thinks the best place to visit Teal is at his farm over on the other side of Buzzards Bay, where he lives with his second wife, Susan Peterson, an anthropologist working at the Oceanographic on fisheries problems.There, he says, the abruptness fades and friendship takes over.

William H. MacLeish is a former editor of Oceanus. *He is now writing a book about Georges Bank and serving the magazine as a Consultant.*

concerns

Navy Studying the Disposal of Old Nuclear Submarines

The U.S. Navy is presently studying the environmental implications of two basic alternatives for permanently disposing of old decommissioned, defueled submarine reactor plants. The alternatives are burial of the reactor plants at a federal land site (Hanford or Savannah River) or sinking entire submarines in deep-water locations that would be selected and approved by the Environmental Protection Agency (EPA). Another alternative would be to store the submarines for an indefinite period under controlled conditions in a Naval shipyard. This is regarded as a "no-action" alternative, only postponing the decision for ultimate disposal.

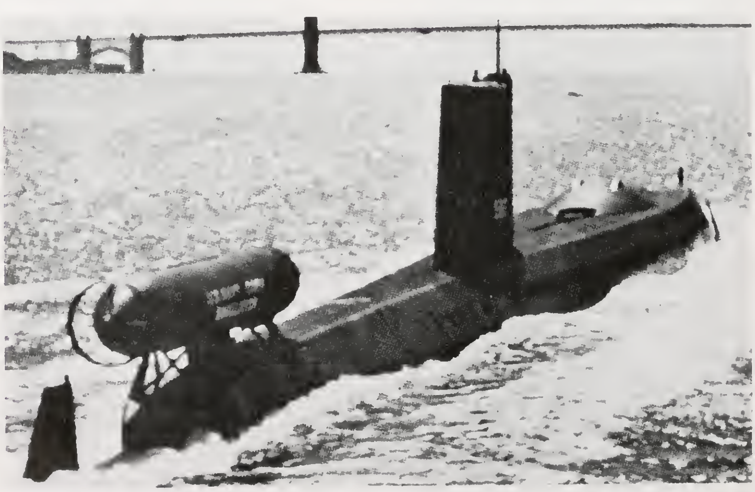
The Navy presently has five publicly known decommissioned nuclear-powered submarines — the *Triton*, the *Halibut*, the *Nautilus* (the first atomic-powered sub), the *Abraham Lincoln*, and the *Theodore Roosevelt*. The *Triton* was retired back in 1967. The *Nautilus* is being prepared as a national memorial. In announcing in the Federal Register of Jan. 14, 1982, its intent to prepare a draft Environmental Impact Statement, the Navy acknowledged that, with more than 100 nuclear-powered submarines in operation, it would be "faced with eventual decommissioning of these ships at a future rate of possibly three or four per year over the next 30 years. . ."

The Register announcement went on to say that the "reactor plants in the submarines do not contain nuclear fuel, transuranic elements, or high-level radioactive material. They will, however, contain low-level radioactivity resulting from the operations of the reactors while the submarines were in commission." A fact sheet prepared by the Navy for members of Congress states that "the only remaining radioactive material [aboard the defueled submarines] is contained within the corrosion resistant metal structure of certain reactor plant components. This radioactivity," it continues, "was created primarily by neutron irradiation of the . . . [stainless steel] components while the reactor was operating."

Science magazine has reported that one defueled submarine reactor could contain 50,000 curies (at time of decommissioning, declining in each subsequent year of storage). The Navy has stated that the predominant radioactive isotope present in the defueled reactor plant is cobalt-60, which decays by a factor of two every 5.3 years, and that "most of these atoms are an integral part of the metal of which some components in the submarine were built." Other typical isotopes present in lesser amounts are iron-55, cobalt-58, chromium-51, manganese-54, iron-59, nickel-63, and nickel-59 (also within integral parts of the structural metals). The Navy says the amount of radioactivity in each defueled submarine is within the limits of the International Atomic Energy Agency (IAEA) for sea disposal of low-level waste. The IAEA limit for beta-gamma radioactivity is 100 curies per metric ton averaged over no more than 1,000 tons.

The Navy stresses that neither basic disposal alternative is favored at this time. It does note, however, that land disposal, though readily available and viable, appears to be a significantly more expensive option.

While the Navy has chosen no exact location for sea



The USS Halibut *in 1970, a nuclear powered guided missile submarine decommissioned in 1975. The craft on her aft deck is a Deep Submergence Rescue Vehicle (DSRV). (U.S. Navy photo from* Jane's Fighting Ships, *1975-76)*

disposal as of this writing, it has used two ocean areas, one in the Atlantic and the other in the Pacific, for generic scientific studies in support of its Environmental Impact Statement. The Atlantic Ocean site is approximately 220 nautical miles southeast of Cape Hatteras, North Carolina, in 5,000 meters of water, and the Pacific area is some 160 nautical miles southwest of Cape Mendocino, California, in 4,200 to 4,500 meters of water. Both areas are thought to be representative of the type of conditions — currents, temperature, geochemistry — that might be encountered if the sea disposal option is selected.

The United States has not permitted the dumping of low-level radioactive wastes in the oceans since 1970, when it yielded to public concern about the possible health effects of the dumping that had been going on since 1946. The Environmental Protection Agency is presently revising its regulations on ocean dumping to allow disposal at sea of toxic chemical as well as radioactive wastes. The dumping of low-level radioactive wastes is not prohibited by the Marine Protection, Research, and Sanctuaries Act of 1972.

The Navy's draft Environmental Impact Statement (EIS) should be available for public comment sometime in the Fall. Following the draft EIS a final Environmental Impact Statement will be issued in about nine months, after which it will take the Navy one to three months more to make a decision on which alternative to pursue.

The Navy has lost two nuclear-powered submarines at sea. The *Thresher* sank on April 10, 1963, in the North Atlantic, approximately 100 miles from land (latitude 40°45'N and longitude 65°00'W) in 2,550 meters of water. The *Scorpion* sank between May 21 and 27, 1968, 400 miles southwest of the Azores in more than 3,000 meters of water. "Radiation measurements, water samples, bottom sediment samples and debris collected from the area where the *Thresher* sank," the Navy says, "were analyzed for radioactivity shortly after the sinking and again in 1965 by various laboratories with highly sensitive equipment. Similarly, seawater and bottom sediment samples taken near the *Scorpion*'s hull were analyzed for radioactivity. None of these samples showed radioactivity above naturally occurring background levels, and none showed evidence of radioactivity released from either *Thresher* or *Scorpion*."

In 1977, followup samples of water, sediment, marine life, and debris were collected from the immediate *Thresher* area. In 1979, a similar followup was conducted for the *Scorpion*. None of these samples showed any evidence of release of radioactivity from the reactor's fuel elements. However, cobalt-60 released from the coolant systems of both submarines was detectable at low levels in sediment samples from localized areas that had not been sampled during the original surveys. The cobalt-60 radioactivity was small compared to naturally occurring radioactivity. Cobalt-60 was not detectable in the samples of water, marine life, or debris near the submarines. This has led the Navy to conclude that the submarines lost at sea "have not had a significant effect on the radioactivity in the environment even though they were lost under catastrophic conditions and with nuclear fuel installed."

The only known case of deliberate disposal at sea of a submarine reactor plant involves the *Seawolf*, one of the first atomic vessels and a craft that President Carter once served on as senior officer. The *Seawolf*'s sodium-cooled reactor was replaced with a water-cooled plant in the late 1950s. On April 8, 1959, components of the sodium-cooled reactor were loaded onto a barge and escorted by the U.S. Coast Guard to a disposal site (approved of by the U.S. Atomic Energy Commission) 120 miles due east of the Delaware-Maryland line. The barge and reactor, with a total 33,000 curies of radioactivity, were then sunk in 2,730 meters of water. The Navy undertook a search for the reactor plant, described as 30 feet tall, in the late 1970s, but could not locate it or the barge, despite using state-of-the-art technology. A Navy spokesman said the service "presumes the reactor is buried in the soft, sea-bottom mud at the disposal site." The Boston Globe, in initially reporting the story in 1980, said that the EPA and other departments had found 80-gallon steel drums of nuclear wastes near the same site that had not sunk into the ocean floor. The drums had been on the bottom for more than 30 years.

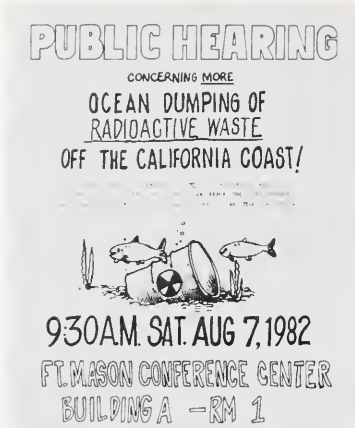
Any decision by the Navy to scuttle its old submarines at sea will have to clear several federal agencies — including the Departments of State and Defense as well as the EPA — and will also be subject to intensive review by Congress. Responsible scientists closely associated with the Navy research program believe that disposing of the submarines at sea is scientifically, technically, and environmentally feasible. G. Ross Heath, Dean of the School of Oceanography at Oregon State University, has helped prepare a series of scientific reports for Sandia National Laboratory and the Navy on the sea disposal option. He commented to this writer: "If you were to catch a fish that had lived close to a scuttled sub for an extended period of time, you would likely find more radiation from natural sources than you would from the submarine." Charles D. Hollister, who was initially contacted by the Navy to start a research program several years ago, is a Senior Scientist in the Department of Geology and Geophysics at the Woods Hole Oceanographic Institution and Dean of Graduate Studies there. He once stated (*Science*, September 26, 1980, p. 1497) that the central concerns yet to be dealt with may be more political than scientific.

Essentially, the possible scuttling of old nuclear submarines fits into a broader environmental debate that will be erupting in the weeks and months to come. The battle lines are drawn: the advocates of ocean dumping contend that there is no significant evidence

that low-level radioactive wastes already disposed of in the oceans have resulted in hazards to the marine environment or to human health. Opponents argue that the scuttling of decommissioned, defueled submarines would give other countries, especially Britain and Japan,* a strong signal that the United States condones littering the oceans with a growing amount of low-level radioactive garbage. They feel that scuttling in general may be the thin edge of the wedge in ocean dumping activity, and that there is still a need for more complete information on past dumping practices. They also are worried that resumption of dumping low-level wastes may eventually lead to the disposal of high-level wastes in the subseabed at deep ocean locations. As one critic put it: "The folks who generate radioactive waste have a perfect record of mismanagement on land, and now they want to try the ocean."

Paul R. Ryan

*European countries, including Britain, are dumping about 100,000 curies a year of low-level radioactive waste at a site in the northeast Atlantic about 550 miles off the tip of Land's End, England. In Britain, the Windscale reprocessing plant releases more than 100,000 curies per year into local waters. Japan is presently planning to dump similar quantities in the Pacific at a point roughly between Japan and the Mariana Islands.



California state Senator Barry Keene of Mendocino County has been a leading opponent of ocean dumping of radioactive waste, including any possible submarine scuttling.

concerns

Big Ocean Science in the 1980s

Large projects and expeditions play a key role in ocean research. The beginning of large-scale ocean science dates from the *H.M.S. Challenger* Expedition (1872-1876). In the years since *Challenger* many major advances have come from expeditions and other large-scale investigations of the ocean and oceanic processes. During the 1970s — the centennial of the *Challenger* — ocean sciences developed especially rapidly in the United States. A key factor was the International Decade of Ocean Exploration (IDOE), which brought new money to the field and new ways of organizing large-scale projects, many of them international in scope. IDOE also brought a flood of acronyms to oceanographers — NORPAX, MODE, POLYMODE, SEATAR, CEPEX, SEAREX, GEOSECS, CUEA — and many others. A few IDOE projects continue to complete their work — MANOP, PRIMA, SEAREX (see the Spring 1980 issue of *Oceanus*).

When IDOE ended in 1980, concern was expressed by individuals and by various advisory groups about continuing into the 1980s the gains made in the 1970s. Specifically, questions were raised about the possibilities of funding new, large interdisciplinary projects after IDOE ended, while avoiding adverse effects on the funding for small-project research.

Since 1980, thirteen new large projects have been initiated by the National Science Foundation's Division of Ocean Sciences (Table 1). Some follow on ideas explored under IDOE funding — SPECMAP and Transient Tracers. Most of the new projects are quite broad, covering several areas of ocean sciences. For example, Warm Core Rings deals with the effects of the rings, spawned by the Gulf

Table 1. Large projects initiated by the National Science Foundation's Division of Ocean Sciences since 1980.

Name/Acronym	Objectives	Began (Duration in years)	Funding $m (other support)
Transient Tracers in the Ocean (TTO)	Understand deep ocean circulation, using man-made tracers in the ocean, including H-3, C-14, Kr-85, Cs-134, chlorofluorocarbons:		
	North Atlantic Study	1980 (4)	6.5 (DOE)
	Tropical Atlantic Study	1982 (3+)	2
Large Aperture Seismic Experiment (LASE)	Develop/test seismic techniques for studying deep structure and stratigraphy of oceanic-continental crustal transition zones.	1980 (3)	2 (Ocean Drilling)
Coastal Ocean Dynamics Experiment (CODE)	Understand processes governing wind-driven ocean circulation over northern California continental shelf.	1980 (4)	6.5
Seasonal Equatorial Atlantic Experiment (SEQUAL)	Observational/theoretical study of responses of equatorial Atlantic Ocean to seasonally varying surface winds.	1982 (4)	4.5
Vertical Transport Experiment (VERTEX)	Investigate vertical transport/exchange of particle-related materials from surface waters.	1980 (3)	3
Pacific Equatorial Dynamics (PEQUOD)	Study circulation of central equatorial Pacific, specifically low-frequency variations in currents, wind-stress-forcing, and equatorial jets.	1980 (5)	7.5
TAG Hydrothermal Field (TAG-2)	Study of hydrothermal circulation in oceanic crust of Mid-Atlantic Ridge, 26°N.	1982 (2)	0.5 (NOAA)
Organization of Persistent Upwelling Structures (OPUS)	Understand role of persistent upwelling structures and relations between circulation and plankton growth.	1981 (2)	0.7
Plankton Rate Processes in Oligotrophic Oceans (PRPOOS)	Determine rates and controlling processes of primary productivity in central oligotrophic gyres.	1982 (2)	0.5
Mapping Variation Spectra (SPECMAP)	Improve understanding of oceanic variability time on scales of 1,000 to 100,000 years.	1981 (4)	2 (ATM/DPP)
Warm Core Rings (WCR)	Investigation of physical, chemical, and biological processes in selected Warm Core Rings in western North Atlantic.	1980 (4)	7
Acoustic Tomography	Develop technique for studying physical features and processes by remote acoustic sensing.	1981 (3)	4.5 (ONR)
Ecology of Hydrothermal Vent Systems	Study ecology and physiology of deep-sea organisms living on hydrothermal vents of East Pacific Rise, 21°N.	1981 (2)	1.5
			$48.7 total

DOE = Department of Energy; NOAA = National Oceanic and Atmospheric Administration; ONR = Office of Naval Research; ATM = Division of Atmospheric Sciences, DPP = Division of Polar Programs (National Science Foundation).

Stream, on the organisms of the slope waters of the western North Atlantic. This study requires several cruises each year by two or three ships to sample rings located and tracked by remote sensing from satellites and aircraft. Maps of sea-surface temperature from satellites are processed by computer and sent within one to two days to the ships to guide their sampling activities.

In the last two years, competition has been tough for projects of all sizes. About a third of the larger projects proposed in 1980-1981 were funded (several after resubmission). About half of the smaller projects were supported. The initiation of so many new projects — many of them expeditions — shows that tight funding for ocean sciences has not eliminated the large-scale studies necessary to understand how the ocean works. And we now have a whole new crop of acronyms to master — LASE, SEQUAL, PEQUOD, PRPOOS, OPUS — with many more to come.

Small research projects (average $80,000 a year) continue to be the backbone of the ocean sciences. There is no reason to believe that the support of new large projects will dry up this valuable component of ocean science research.

The new projects have already begun to make their mark. Studies of hydrothermal vent organisms have been featured on prime-time television. And we look forward to more exciting results.

M. Grant Gross, Director, Division of Ocean Sciences, National Science Foundation, Washington, D.C.

letters

To the Editor:

I am writing to tell you how much I enjoyed the article on palytoxin in the summer issue. It read like a detective novel, and held my interest to the last page. What a triumph of scientific investigation!

My enthusiasm is touched with unease, however, when I consider how fragile such an undertaking is, and how much it depends upon the continued availability of funds from government sources, which are rapidly becoming depleted. I wonder if there has been any enthusiasm for searching out new sources of revenue for such projects through commercial enterprise, such as fish farming, seabed mining, etc. If so, that would make a good subject for further articles.

Matthew Cushing Jr., M.D.
Andover, Massachusetts

To the Editor:

I wish you had been a little more critical of the article written by Thomas D. Galloway and Dennis Nixon — "The Newest Federalism and Coastal Areas." I think some of these liberals should have a little more sound information before spouting off. I think we do a pretty good job along these lines on the coast of New Jersey without relying on the federal government to accomplish everything. Lots of big words but not much practical thought. Maybe they think Teddy Kennedy and their friend Senator Pell are smarter than some of the rest of us.

F. W. Roebling, III
Trenton, New Jersey

To the Editor:

I noted with interest your editorial comments under "Changing the Watch" in the Spring 1982 issue of *Oceanus*, particularly as concerns the new direction you are contemplating for the magazine. I have been a subscriber for only about one year, but even with only four issues to date on which to base the remarks to follow, there are nevertheless a few suggestions I would like to offer.

First, I think it would be wise to consider taking steps to broaden the appeal of the magazine for the interested lay public. While I do not think that the technical level of the articles I have read so far is too advanced for the lay readership, I do feel that a strict adherence to the present monothematic format is a mistake. I am in favor of adopting some of the suggestions sent in by other readers, as outlined in your editorial. A news section on current oceanographic developments is an excellent idea. Such a department might be organized on an institution-by-institution basis (Woods Hole, Scripps, MBL, Rosenstiel, and other major oceanographic schools), a discipline-by-discipline basis, or a combination of the two. News of ongoing oceanographic research from other countries would be a welcome addition, too.

Book reviews, biographical profiles, letters to the editor, and a forum for presenting arguments from both sides of controversial issues are all good suggestions as well. I would also like to see a shift in emphasis from political, economic, and technological topics to more in the way of marine science and its relationships to all the other natural sciences, although this is just a personal preference.

One of the best ways to stimulate more public interest in the magazine would be to incorporate some color. I know this has been suggested before by others, and I am acutely aware of the expense involved in 4-color printing (I am employed in the printing industry). But color printing, at least on the covers, would do a lot to enhance the attractiveness of the magazine, and perhaps the additional expense could be defrayed by accepting display advertisers.

Whether you decide to take the direction of my recommendations or not, I wish you and *Oceanus* every success, and you may be assured of my continued interest and support.

John E. Quatchak
Pittsburgh, Pennsylvania

To the Editor:

Do not change the format of *Oceanus* without a large justification. In my opinion, *Oceanus* has a structure which facilitates a speedy and informative overview of ocean sciences. I would be very disappointed if *Oceanus* became a leisurely magazine (a magazine which takes a long time to browse through). If significant sales could be obtained by cluttering up the magazine, then you might consider publishing a separate magazine which contains this clutter and make a nice profit. Otherwise, why burden your present subscribers with the clutter they presently are willing to live without?

Before changing *Oceanus*, determine the objective of this publication, then weigh each new idea with the overall objective. If the new idea strengthens the objective, then use it. If it does *not strengthen* the objective then disregard it. Good luck in the years ahead.

George R. French
South Berwick, Maine

P.S. — I have received 27 issues of *Oceanus* to date and it is the *only* publication I read from cover to cover. *That* is saying a lot!

To the Editor:

I think it's a good idea to expand the contents of your magazine, but not too much. A news section on current oceanographic development is a great idea. Readers, like myself, want to know what's going on. Letters to the editor

Letters Policy

The editors of Oceanus *urge you (our readers) to write us about any concerns you may have involving oceanic matters. These letters can be on any topic — ranging from reactions to specific articles in the current or a past issue to matters in the marine field that you feel should be brought to the attention of the oceanographic community. The letters, if selected for publication, are subject to editing because of space limitations. We promise to be as judicious as possible.*

— won't that be fun — sounds fairly good as long as it doesn't get carried away.

Profiles of selected oceanographers in different fields — *in different fields* — of oceanography sounds interesting. I know I would love to know the different aspects of oceanography and the people in it.

Pro and con arguments on controversial issues, I'm not too thrilled about. You hear so much on pro and con issues — I'm sick of it!!! Book reviews sounds like *The New York Times,* not a magazine about the ocean.

The displaying of advertisements could help with funding, but I hope you have a person who is choosey about the advertisements that go into every issue. You could lose or gain readers that way. Well, you wanted my opinion and here it is. I hope it helps you decide.

Carolyn Kaetz
Paramus, New Jersey

To the Editor:

Taking you at your word, as published in the Spring '82 issue of *Oceanus,* I put pen to paper in an attempt to address some of the issues you raise.

I suppose I should preface my comments by providing some information about myself so that you may better place my remarks in perspective. I am an active duty Lieutenant Commander in the U.S. Navy with little formal education in oceanography but with a deep respect for and love of ships and the sea. (It was, in fact, my continuing and growing interest in the sea that brought me in contact with *Oceanus.*) My technical education has enabled me to follow your articles with little difficulty, and on the most part I have enjoyed them. Also, I am a member of other professional societies with concerns similar to those that you discuss in your open letter.

How then does one in fact broaden one's scope to provide worthwhile information to the widest qualified audience without watering down the effort? I for one would very much welcome and favor all the ideas put forward in paragraph two of your notice. In addition, I would suggest the following. Besides formal reviews of books, possibly a page could be devoted to a list of newly published books in the field, with a quick "dust jacket" description, the publisher's name, and price information. In the area of ever-expanding ocean science, I believe this would prove invaluable. As I'm sure you understand, the field is difficult to stay current in. A book section in *Oceanus* would enable the enthusiast to stay somewhat caught up with his academic brethren as they read the latest literature.

My second suggestion is much broader and far-reaching — possibly outside the scope of your request. It seems that the oceanographic community in particular and novice-enthusiast amateurs, like myself, in general would be well served by a professional society that devotes itself to the scientific study of the sea. What better place for it to thrive than Woods Hole, what better journal than *Oceanus*? Technical difficulties will certainly present themselves (funding, charter, tax status, etc.), but none of these is beyond being managed. Certainly the community is large enough to support and foster such an effort. In time, I would like to see the "American Society of Oceanography and Related Sciences" (If you're not keen on the name, I'm sure you'll be able to come up with something that better suits your taste) publish its own books and conduct seminars, etc.

A publishing effort, for example, could involve the theme of your spring issue. It appears that Jane's has abandoned *Ocean Technology* (the last issue published was 1979-80) for some reason. Too, the now defunct effort by the IGY World Data Center for Oceanography and the National Oceanographic Data Center to publish *Oceanographic Vessels of the World* leaves a major vacuum in the field. As the spring issue of *Oceanus* points out so well, specifically by Messrs. D. W. Spencer and R. Dinsmore, ships make up the backbone of the effort but little is known about them or how to coordinate their activities. Something needs to be done, and I suggest no one is in a better position than *Oceanus.*

I recognize these projects are very ambitious and require much money and time to get off the ground, or should I say into the water. Nonetheless I strongly believe they are worth doing and possible. Again I say *Oceanus* is the proper place to have it all start.

One last thought on an area to which I think you should direct your efforts. The United Nations efforts with regard to the Law of the Sea need to be openly discussed by members of the scientific community. With more support, I believe the U.S. would come around and support the treaty.

Whichever course you elect to take with *Oceanus,* my best wishes go with you. I will look forward to good things. Good luck.

LCDR Robert E. McCabe
U.S.S. Towers
South China Sea

P.S. — Please forgive my penmanship — it's a little choppy out here tonight.

To the Editor:

The recent article "From Antiquity Onward" by G. C. Ewing, in the Fall '81 *Oceanus,* was an extremely informative, precise piece of oceanographic literature. Thank you.

M. R. Grochowske
Warm Springs, Georgia

To the Editor:

I enjoyed your *Oceanus* Spring 1982 issue very much on the great and beautiful research vessels of the sea. I have enjoyed almost all of your issues. Keep up the good work!

Paul Ritchey
Leesburg, Virginia

To the Editor:

. . . And the tide rises, and the tide falls. Best wishes to Bill on his chosen voyage and congratulations to you and Ben, your crew, for having the opportunity to take the helm.

Some six years ago I found myself at something of a crossroads — all of us are confronted with similar episodes at varying intervals within our lifetimes. My situation was centered about the vocation/avocation dilemma. An avid scuba diver and active member of the Long Island Sound Chapter of the Oceanic Society, it seemed natural to pursue my oceanographic interests into a career.

My infinite free spirit being resolved to the finite by those restrictive responsibilities that are a growing family — and the associated economic attachments therewith — I reluctantly chose to pursue a degree in electronic engineering. My undergraduate work is soon to be complete; in the meantime, my regulator has occasioned an annual workout for a day or so in August when I experience a week of freedom from either professional or academic demands.

Two major contributing factors in my successful completion of attaining my degree have been *Sea Grant* and *Oceanus;* the former to keep me abreast of the wide range of accomplishments and the latter for its in-depth pursuit of particular aspects of oceanography. As there are many facets to every crystal, if one is to fully appreciate the interrelationships of those elements that comprise that complexity which we call the ocean, one must first study singular subjects. Not being one to view such topics in the mystical fashion of Cousteau, I relied on *Oceanus* to supply me with accurate, scientifically detailed accountings of the differentiated whole.

To date, I feel that my benefits have greatly exceeded my contribution to you. It requires both confidence and competence to properly communicate the issues that you handle — and they have been handled extremely well. I pray that any modification you might make in your dedication to this communication should perhaps appear in the form of a newsletter as a supplement to the present treasure that is *Oceanus.*

Christopher H. Rogalin
Danbury, Connecticut

To the Editor:

It is with considerable hesitation that I reply to your request for "thoughts" on the character of *Oceanus.* I strongly advocated the change from Jan Hahn's "house organ" to what has become *Oceanus.* The journal befits the Institution in a very special and most excellent way. It is really one of the best of the "scientific" journals. For some time, "just for ducks," I have been trying to think how it could be expanded without detracting from its contribution to science through its very proper emphasis on the broad range of oceanography. Frankly, some of the articles mean very little to me, for they talk of things that a retired archaeologist has never heard of. Nevertheless, I am quite certain they contribute to the science and that they must be published. I suspect oceanographers will let editors and authors know in no uncertain terms when some article goes off the deep end. That kind of bitter pill can be good for everyone.

So many journals have sought refuge in the things you mention in the hope of increasing circulation. It always seems to me that these detract from the real purpose of the magazine, especially when these "departments" get out of hand. Is there evidence that these departments increase the income or number of readers or, more simply, enhance or broaden the interest in a journal? Does the approach to the gossip level (a "News" column) really do any good? Advertising is something else of course; it does increase income if the overhead is not too high. I would urge restraint insofar as possible. Book reviews, yes indeed; good ones, even of bad books, are interesting and useful and more could be published in *Oceanus.* Letters and pro and con arguments, especially on published materials, rarely contribute very much. They are often out of date because of publication schedules, and sometimes the problems they address are of limited interest, and they can partake of self-aggrandisement. Given a stated department, it is very difficult to turn down inappropriate letters. Also, matters discussed in this way are often to be found in almost unretrievable back numbers. I ran a news section in an archaeological journal long ago and remember growlings involving personality problems, inadvertent omissions, publication of incorrect information received, and above all problems with timing. I doubt if this endeavor was of much value. It seems to me that restricted and carefully solicited and selected material of this kind can be of interest if published occasionally on the basis of merit as "editor's comments" or by some such device that makes possible the distribution of relevant and timely material in pieces that are analogous to the regular articles.

What I really started to talk about is the expansion of *Oceanus* by publication of interpretive-type articles directed to the informed layman. An example may be the recent issue on "Research Vessels," the reading of which I anticipate with pleasure. However, it is hardly necessary to devote a single issue to such a subject unless, as it seems in this case, the subject matter justifies it. I am well acquainted with the difficulty a scientist has in trying to explain what he is doing and what his objectives may be in a way that appeals to people who would either like to learn or who would be happily surprised if they accidentally did. I am not advocating the popular article but something a cut or two above that.

I look forward to developments in the editorial policy of the journal that will supplement but in no way replace or detract from the kind of material that is now being presented.

Frederick Johnson
Andover, Massachusetts

To the Editor:

The *Oceanus* issue entitled "Oceanography from Space" (Fall 1981) contains an article by Robert H. Stewart, "Satellite Oceanography: The Instruments." There are some statements made about the passive optical instruments that sense in the visible and in the infrared which are sufficiently general or in error to such a degree that they might confuse a prospective user of data from one or more of the optical sensors. The statement is made that the visible and infrared instruments work much like television cameras, with only technical differences. There are quite significant differences that should be understood by any prospective user of the data.

It is, perhaps, most useful to group the instruments by three separate types. The Advanced Vidicon Camera System (AVCS) and the Return Beam Vidicon (RBV) are the most like television systems of all the types, in that they do use a vidicon. They do not, however, operate like a conventional television camera, in that the scene is not imaged continually on the vidicon and read out many times per second as in a conventional TV system. The AVCS and the RBV both utilize a lens and a shutter so that a picture is snapped much like a conventional camera, and the image is

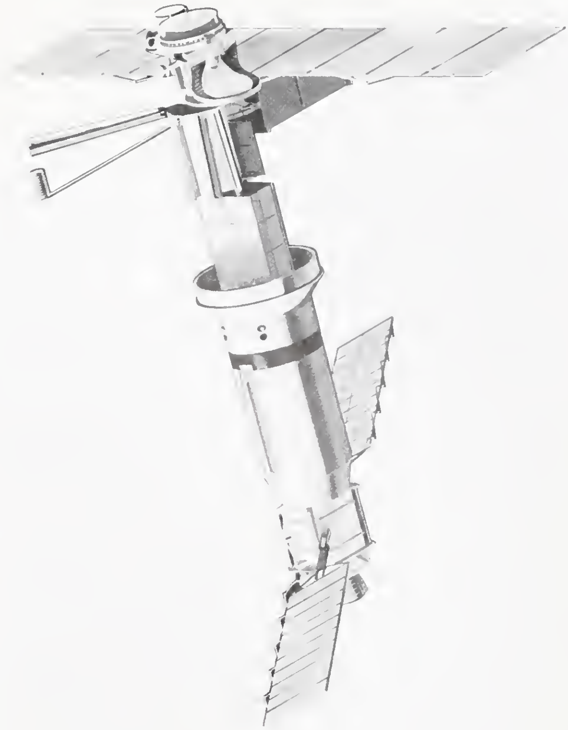
then read out from the vidicon in between individual exposures. The AVCS field of view is 37 degrees square, and the RBV field of view is 11.2 degrees square. In an instrument such as the RBV or the AVCS, all of the picture elements are viewed simultaneously so that objects on a surface are viewed in forward, normal, or backscattering, depending on the location relative to the subsatellite point.

With the exception of the Visible Infrared Spin Scan Radiometer (VISSR) all of the other passive optical sensors listed by Dr. Stewart belong to the same general class. They are all electromechanical sensors, more popularly called multi-spectral scanning radiometers. All of them collect either reflected solar radiation or emitted thermal radiation, with a folded reflecting telescope, and utilize either a fully rotating mirror at 45 degrees in front of the telescope or a mirror that rocks back and forth in a so-called butterfly valve motion. An image is built up by scanning from one to six lines perpendicular to the spacecraft's line of flight each time the mirror rocks or rotates. The spacecraft provides one direction of the scan by its velocity in orbit, and the mirrors are designed to rotate or rock to produce contiguous lines from which the eventual image is constructed. Most of the optical instruments mentioned scan one scan line at a time, but the Multi-Spectral Scanner (MSS) on Landsat scans six scan lines each time the mirror rocks in each of the four spectral bands sensing reflected solar radiation.

The important difference between these electromechanical scanners and the vidicon scanners is the fact that the surface of Earth is viewed in the same geometry with each scan of the sensor. A good example of the difference one would see is that either the AVCS or the RBV, operating over the ocean with the specular reflectance point of the sun in the field of view, would show a large glint pattern as a roughly circular, bright image. The electromechanical scanners of the type flown on the polar orbiting satellites, such as the Coastal Zone Color Scanner (CZCS) on Nimbus-7, would show the glint pattern to be a bright bar running parallel to the spacecraft's line of flight. The CZCS has one unique feature in that the scan mirror can be tilted to look either ahead or behind the spacecraft in two-degree increments up to 20 degrees, to avoid the glint. Once the tilt has been set as a function of sun elevation, it is not changed during the acquisition of any one scene. Another difference between the vidicon-type sensors and the electromechanical scanners is that, since the vidicon instruments snap a picture at a particular period of time, objects within the scene (except for optical distortions in the instrument) bear a true relation to each other in geometry. Since the electromechanical sensors acquire an image by operating continuously as a spacecraft proceeds in its orbit, the roll, pitch, and yaw of the spacecraft will introduce distortions in addition to those produced by the optical system.

A possible misprint occurs on page 69 of Dr. Stewart's article, where the statement is made that the Multi-Spectral Scanner on the Landsat series produces pictures 100 kilometers across. The swathwidth of the MSS is in fact 186 kilometers, or 100 nautical miles, which perhaps led to the error.

The last type of instrument, the VISSR from the Geostationary Observational Environmental Satellite (GOES) series, is also an electromechanical scanner, but since the spacecraft itself is in geostationary orbit, remaining over one point on the Equator at an altitude of approximately 35,800 kilometers, its method and geometry of scanning are different from all the others. The VISSR uses the rotation of the spacecraft (100 revolutions per minute) and a spin axis parallel to the rotational axis of Earth to



produce scan lines parallel to the Equator. Each time the spacecraft spins, eight lines are scanned in the reflected solar region of the sensor (0.54 to 0.7 micrometers) and one line is scanned in the thermal infrared region (from 10.5 to 12.6 micrometers). After the earth-scan of approximately 20 degrees, a large, flat, eliptically-shaped mirror steps 0.2 milliradians to provide a contiguous scan on the next rotation. The earth is then scanned from pole to pole. The geometry of the imagery from VISSR is thus quite different from that acquired with the other electromechanical scanners on polar orbiting satellites, and is somewhat like that acquired with the vidicon sensors, with the exceptions that the pixel elements are not viewed simultaneously and that only the subsatellite point at the Equator is ever seen at the normal. The glint pattern as observed with the VISSR instrument is nearly circular in shape, much like that seen with the AVCS and the RBV. Because the GOES satellite must fly over the Equator to be geostationary, serious foreshortening arises in high latitudes, so the usefulness of the data for these latitudes is reduced for oceanographic purposes.

The purpose of this letter is not to nitpick the articles in the Oceanography from Space issue, but to attempt to inform oceanographers who may be just beginning to utilize satellite data in their research that the sensors differ materially in the way they collect data, in their geometrical considerations, and in the way their data must be interpreted in light of these considerations. Data from most of these sensors is available on magnetic tape and is usually read out on a line-by-line or scan-by-scan basis by image analyzers or computers. If an investigator is not familiar with the method in which the data was collected, serious mistakes in interpretation could occur, since it is not immediately obvious from the magnetic tape data that the three types of sensors are so different in their methods of producing imagery.

Warren A. Hovis, Director
NOAA Satellite Experiment Laboratory, Washington, D.C.

book reviews

Introduction to Oceanography by David A. Ross. 1982 (Third Edition). Prentice-Hall, Inc., Englewood Cliffs, N.J. 544 pp. $25.95.
Oceanography: A View of the Earth by M. Grant Gross. 1982 (Third Edition). Prentice-Hall, Inc., Englewood Cliffs, N.J. 544 pp. $25.95.
Introductory Oceanography by Harold V. Thurman. 1981 (Third Edition). Charles E. Merrill Publishing Co., Columbus, Ohio. 464 pp. $24.95.

A few years ago, there seemed to be a lack of good introductory textbooks on oceanography for senior high school and college students. Recently, however, three fine books have come to my attention.

Introduction to Oceanography by David A. Ross. Dr. Ross has broken away from the traditional format of most textbooks. In this newly revised volume, he begins with an excellent introduction, followed by a brief history of the subject. While few textbooks deal with instrumentation and techniques of the field, Dr. Ross devotes an entire chapter to this subject. Discussion of the effects of oceans on climate — in particular the North Pacific Experiment (NORPAX) program and the carbon dioxide problem — is of interest to students and nonstudents alike. One key chapter deals with the Law of the Sea conferences, a topic that many texts give only cursory treatment. The chapters on biological, chemical, and physical oceanography have brief histories that help to put recent findings into a better perspective.

Each chapter ends with a useful summary and suggested further readings, many of which are from current periodicals, making them fairly easy to find in libraries. The book is well illustrated with pertinent photographs and clear line drawings. This volume would make an excellent addition to anyone's library.

Oceanography: A View of the Earth by M. Grant Gross. Many teachers of oceanography will welcome Dr. Gross' newly revised volume, which has become a classic in the field. This large-format textbook considers all the traditional subject matter expected in this sort of book. Dr. Gross makes some interesting departures from the usual format. For example, rather than treating biological oceanography all at once, he devotes three chapters to this subject. The first concerns oceanic life, the second covers plankton and fish (marine food webs), and the third discusses the benthos. I found this type of treatment excellent, as many teachers are seeking to deal with topics from a systems approach.

Another interesting aspect of the book is the appendix of graphs, charts, and maps. A large percentage of the work undertaken by oceanographers requires an understanding of such diagrams. In step with today's widespread interest in ecology, Dr. Gross devotes a chapter to fisheries, whaling, resources from seawater, petroleum, natural gas, and minerals. The chapters end with review questions, a summary outline, and selected references. I found some of the drawings to be of questionable quality, but the illustrations, overall, are certainly fine. This book would be excellent for advanced senior high school and college students.

Introductory Oceanography by Harold V. Thurman. Dr. Thurman's large-format volume also covers the broad range of topics expected in a textbook. His chapter on the history of oceanography covers the concepts of geography as they relate to the field of ocean studies. In this day of increased emphasis on the science of the oceans, it is appropriate to recall that oceanography began with people interested in navigating from one place to the other for commercial purposes. Dr. Thurman emphasizes marine geology, covering the origin of ocean basins, plate tectonics, growth of ocean basins, and the geology of coastal regions. His presentation of biological oceanography is interestingly different, dealing with biological productivity and energy transfer. The "Special Feature" sections concern concepts the author felt needed extra attention. These are "three-color inserts," designed to enhance the student's interest. At the end of each chapter is a good summary, with some questions and exercises, references, and suggested readings. All of the suggested readings can be found in *Sea Frontiers* and *Scientific American*. The book is up to date, well documented, well illustrated, and would certainly be useful to high school seniors and to those taking introductory college courses.

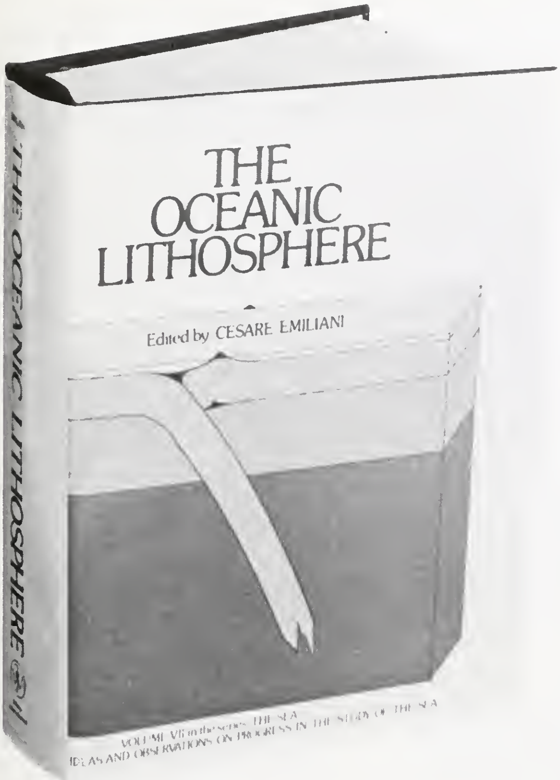
Which one to pick? This is a hard decision indeed. I suggest that teachers ask for review copies and carefully look them over to see just how each book fits into your way of teaching, your interest areas, and the goals you have set for your course.

Prentice K. Stout,
Marine Education Specialist,
University of Rhode Island

The Sea, Vol. 7: The Oceanic Lithosphere, Cesare Emilani, ed. 1981. Wiley-Interscience, New York, N.Y., 1,738 pp. $175.00

This is an excellent book, but it has a price clearly beyond the reach of even the most affluent marine scientist, and so must be classed as a library reference book. It is the latest in a series begun nearly 20 years ago under the rubric: "The Sea: ideas and observations on progress in the study of the seas." It is about as thick a book as can be bound in a single volume, measuring 7¼ x 10¾ inches. It has 35 chapters and 55 contributors, nearly all of whom are American.

The term "oceanic lithosphere" here means material of the upper mantle and above. Forty percent of the text is devoted to the upper mantle and crust and 60 percent to the sediments. Each chapter is essentially an up-to-date review article



written in a clear, comprehensive, and authoritative manner, and illustrated. Topics related to upper mantle and crust include geochemistry, convection, rocks of the oceanic crust, ophiolites, magnetism, heat flow, hot spots, hydrothermal activity, metal deposits, and more. Topics related to sediments include their distribution; the components supplied by winds, rivers, or extraterrestrially; authigenic oxides and silicates; phosphorites; foraminifera (both planktonic and benthic); radiolaria; nannofossils; diatoms; tephrochronology; stable isotopes; paleoceanography; sea level changes, physical properties of the sediments, and others. In addition, there is an excellent introduction by Roger Revelle; he asks 10 major questions about the oceanic lithosphere that we are still trying to answer today. There is an equally appropriate conclusion and dedication by Cesare Emiliani; in his refreshing style he discusses how we have reached our present state of knowledge about the oceanic lithosphere over the last 30 years. It is unfortunate that marine scientists cannot afford to have this volume on their own bookshelves, for it deserves to be there.

This reviewer just purchased a volume of comparable size from the University of Wisconsin Press (*Antarctic Geoscience*, C. Craddock, ed. 1982. 1,216 pp., 151 chapters) for $35, or 2.9 cents per page, and wonders why Wiley-Interscience must charge more than three times as much for *The Oceanic Lithosphere*.

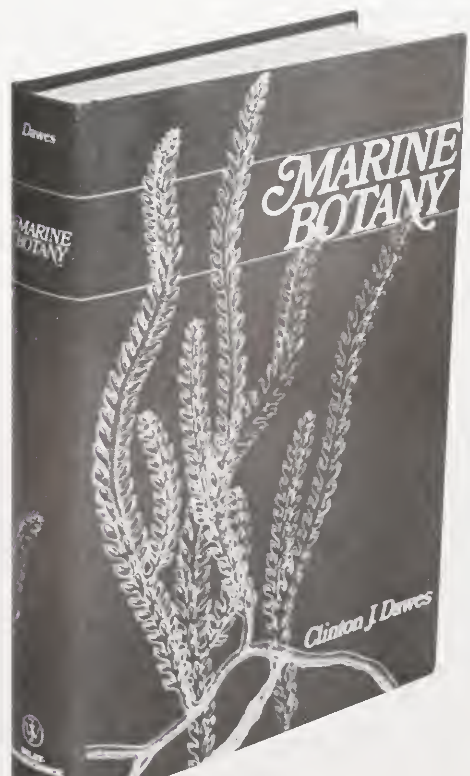
J. R. Heirtzler, Senior Scientist
Woods Hole Oceanographic Institution

Marine Botany **by Clinton J. Dawes. 1981. Wiley-Interscience, New York, N.Y., 628 pp. $45.00.**

Marine algae are a broadly diverse group of plants, with some 8,000 species and a very wide range of biochemical, physiological, and life history characteristics. Describing the algae would be a considerable effort in itself in a text of this size, but the subject of marine botany does not end with algae. A small but very important group of terrestrial plants has invaded the sea, constituting the foundation of three important ecosystems along the ocean margin: seagrass meadows, salt marshes, and mangrove forests.

At 628 pages, ***Marine Botany*** is more than an introduction, but given the breadth of its task it cannot be expected to be completely comprehensive. Condensing a broad field necessarily becomes a question of the author's choice of emphasis, and Dawes focuses on ecological aspects of marine botany. This is the first book on this topic since E. Yale Dawson's *Marine Botany: An Introduction* (1966), and a great deal has been accomplished in the interim. Dawes hasn't the beautifully simple writing style of Dawson, but successfully compensates with a more thorough text. This newer work is directed at a more knowledgeable audience.

Dawes' introduction consists of the obligatory reiteration of the importance of marine plants. Never mind the fact that oceans cover three-quarters of the earth's surface, and that the plants in and around the ocean account for roughly half of the world's photosynthesis. Dawes presents an essentially



encyclopedic listing of the economic applications of algae: algae for food and emulsifiers as well as recent developments like biogas.

The second section focuses on marine algae; the treatment of the eight major divisions of algae is based on the system of Bold and Wynne (1978). It contains 176 figures and many fine drawings and photomicrographs of representative species. A tabulation summarizing the algal genera and their distribution would have been a useful addition to this section. Dawes does include concise appendices on marine fungi, lichens, and bacteria.

The third section, "Ecological and Environmental Considerations," might better have preceded the section on algae, thereby introducing the environment before introducing the species. This section is essentially a review of oceanography, emphasizing near-shore processes. It also serves as a field manual, with extended descriptions of techniques. These are distractions in the flow of the text and ought to be in appendices.

The book is designed to build towards the final section, with chapters on the six most-studied marine plant communities (lithophytic, coral reefs, seagrass meadows, salt marshes, mangrove forests, and phytoplankton communities). The discussion is well presented and well illustrated, and has useful tables summarizing data. Perhaps the weakest chapter is that dealing with phytoplankton. Considering Dawes' ecological thrust, it is disappointing to find phytoplankton seasonal succession is given only one page.

Specialists will find their disciplines well reviewed, but with a preponderance of references from recent publications. This allows the new researcher to get up to date immediately, but tends to bypass the papers making original breakthroughs. *Marine Botany* therefore will be especially useful as a text for late undergraduates and early graduate students, and as a reference for oceanographers in general.

John W. H. Dacey, Assistant Scientist,
Woods Hole Oceanographic Institution

Books Received

Biology

Introduction to Fish Physiology **by Lynwood S. Smith. 1982. T. F. H. Publications, Inc., Neptune, N.J. 256 pp. $19.95.**

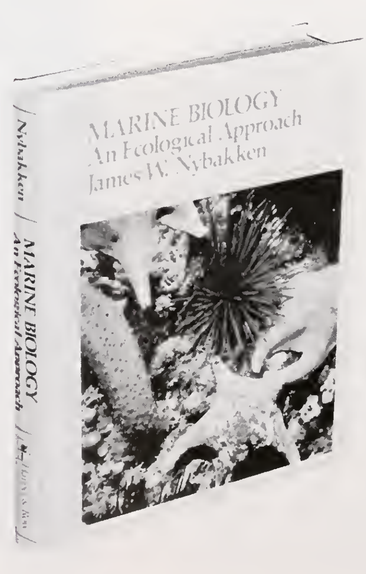
From the press release: In this volume, Dr. Smith describes how fishes' organs function. Using line drawings, charts, and photographs, the text explains . . . experimental data illustrating the unusual physiological functions of fishes that have no counterpart in man. Technical language is avoided as much as possible.

Fisheries Ecology **by Tony J. Pitcher and Paul J. B. Hart. 1982. AVI Publishing Co., Westport, Conn. 414 pp. $32.50.**

Concerned with the ecology of exploited fish populations, this book differs from existing texts in its broad view of the subject, considering fish as elements in a delicately balanced ecosystem. Also included: a look at the adaptive behavior and physiology of fishes, and the economics of fisheries. The book is meant as a text for senior undergraduates in zoology or ecology, as well as specialists in fisheries.

Marine Biology: An Ecological Approach **by James W. Nybakken. 1982. Harper & Row, Inc., New York, N.Y. 446 pp. $26.95.**

This is a text designed for the undergraduate in marine biology; it requires very little scientific background. The book stresses ecological processes and adaptations that work to structure marine associations and permit their persistence through time.



Common Plants of the Mid-Atlantic Coast, a Field Guide **by Gene M. Silberhorn; illustrated by Mary Warinner. 1982. The Johns Hopkins University Press, Baltimore, Md. 256 pp. $17.50 hardcover; $7.95 paperback.**

Written for those who want to know more about common plants of the Mid-Atlantic coastal region, extending from Long Island Sound to South Carolina's barrier islands, this book is divided according to the natural divisions of the landscape: beaches, dunes, and marine forests; salt and brackish marshes; and tidal and non-tidal freshwater wetlands. Included is a list of parks and regions where the plants are found. Technical language is used only when necessary, and is often explained in the text.

Organic Materials in Aquatic Ecosystems **by Humitake Seki. 1982. CRC Press, Inc., Boca Raton, Fla. 201 pp. $64.00.**

From the introduction: In [an] aquatic ecosystem, organic materials are produced primarily by photosynthetic activity. Some fraction . . . is transferred . . . to herbivores and then to carnivores within the ecosystem. The rest is discarded as . . . organic debris . . . . [which] is further transformed into

viable organic materials through the detritus food chains . . . . organic materials in the ecosystem are exposed to an endless series of changes which continue as long as organisms continue to live in the system . . . .

Trends in Fish Utilization **by J. J. Connell and R. Hardy. 1982. Fishing News Book, Ltd., Farnham, Surrey, England. 103 pp. £6.00 plus 60p postage.**

The aim of this book is to examine how Britain can make the most of the unused or little-used marine animal resources available to it, but the conclusions reached by the authors could have worldwide application.

***Marine Ecology: A Comprehensive, Integrated Treatise on Life in Oceans and Coastal Waters*. 1982. Volume 5. *Ocean Management,* Otto Kinne, ed. Part 1. Zonations and Organismic Assemblages. John Wiley & Sons, Ltd., Inc., Somerset, N.J. 642 pp. $89.95.**

Part 1 of Volume 5 of *Marine Ecology* concerns the description, analysis, and evaluation of zonations and assemblages, or the groups of species (populations) living together in a defined place or environment.

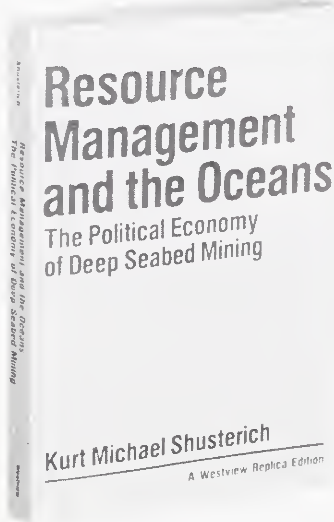
Seals and Man: A Study of Interactions **by W. Nigel Bonner. 1982. Washington Sea Grant, University of Washington Press, Seattle, Wash. 170 pp. $9.95.**

From the press release: In this book, the author . . . describes man's long and varied relationship with these animals, including the effect of seals on fisheries and the commercial industry's impact on the seals themselves. Aspects of seal biology, social structure, breeding, and diet are described.

Ecology of Coastal Waters: A Systems Approach **by K. H. Mann. 1982. Studies in Ecology Volume 8, University of California Press, Berkeley, Calif. 322 pp. $36.00 (hardcover); $18.00 (paperback).**

This book concentrates on ecological processes, rather than organisms or populations. The principles of the systems approach to coastal ecology are enunciated and key references given.

Marine Policy



Resource Management and the Oceans: The Political Economy of Deep Seabed Mining **by Kurt Michael Shusterich. 1982. Westview Press, Inc., Boulder, Colo. 344 pp. $22.50.**

From the preface: This book analyzes . . . domestic and international issues . . . raised about the management of the global commons . . . . focusing on the case of deep seabed mining, while pointing to the broader range of political implications . . . .The book was completed just as the 11th and final session of the Third United Nations Conference on Law of the Sea came to a conclusion, on April 30, 1982 . . . . the uncertain future of the Law of the Sea Treaty suggests the need for a careful reading of the complex issues addressed in this book.

Balancing Unknowns: A Decade of Controversy About Developing the Outer Continental Shelf **by H. William Menard. 1982. Washington Sea Grant, Seattle, Wash. 25 pp. $3.00.**

Menard stresses the need to develop as quickly as possible a reliable inventory of both oil and gas reserves for use in national policy planning. He advocates simplifying leasing procedures and concludes that exploiting the Outer Continental Shelf has the potential to help solve the nation's energy problems with less stress to the environment than any comparable alternative.

Aquaculture

Aquaculture Development in Less Developed Countries: Social, Economic, and Political Problems, **Leah J. Smith and Susan Peterson, eds. 1982. Westview Press, Inc., Boulder, Colo. 152 pp. $22.50.**

From the book: Aquaculture may not be the panacea for the world's food problems, but it has the potential to make important contributions to diet and income in some areas. This book, intended to improve planning for further development of aquaculture, examines the factors that can determine the success or failure of aquaculture projects in developing countries.

The Biology and Culture of Tilapias, **R. S. V. Pullin and R. H. Lowe-McConnell, eds. 1982. International Center for Living Aquatic Resources Management, Manila, Philippines. 432 pp. Price Not Given.**

Tilapias are a major protein source in many developing countries. They are well suited to culture for a number of reasons, including widespread acceptance as food fish. However, there are problems in the rearing and general husbandry of tilapias, resulting from an inadequate research base on their basic biology. Nineteen tilapia biologists from 10 countries present 15 papers under three headings: Biology, Physiology, and Culture.

Energy and Environment

North Sea Oil and Environmental Planning: The United Kingdom Experience **by Ian R. Manners. 1982. The University of Texas Press, Austin, Tex. 332 pp. $37.50.**

From the jacket: . . . offshore drilling is now taking place in . . . areas where . . . conditions and problems of supply and transportation pose a formidable challenge. The book details how Britain is dealing with the "technological frontier" of oil production in an area where equipment must cope with mammoth waves and seabeds of quicksand and mud. The author raises issues of particular importance in the United States,

where the intense national debate over energy needs and environmental safeguards continues.

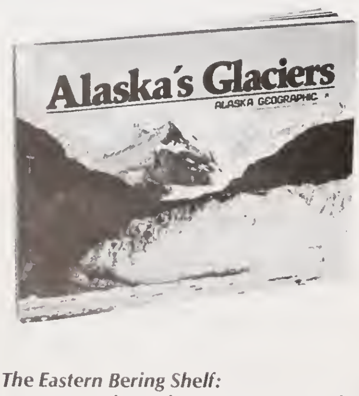
Tidal Energy by **Roger H. Charlier. 1982. Van Nostrand Reinhold, New York, N.Y. 336 pp. $28.00.**

From the jacket: *Tidal Energy* demonstrates the advantages of using the ocean as an energy source — it is virtually limitless and nonpolluting — and looks at the possibilities of building tidal power schemes in developing countries .... [includes] information on what causes tides, how tides are used to generate electricity, and the locations of hundreds of potential sites for tidal power plants.

Geology and Geography

***Alaska's Glaciers,* Robert A. Henning, Barbara Olds, and Penny Rennik, eds. 1982. The Alaska Geographic Society, Anchorage. Alaska Geographic, Volume 9, Number 1. 144 pp. $9.95, plus $1.00 postage.**

The main text of this book is by Dr. Bruce Molnia of the U.S. Geological Survey. Included are chapters explaining glacial types and formation, the movement and effect of glaciers on the earth's crust, and the specific glaciers and glacial regions of Alaska. The book is illustrated throughout with color photographs and maps.



***The Eastern Bering Shelf: Oceanography and Resources,* Donald W. Hood and John A. Calder, eds. 1982. University of Washington Press, Seattle, Wash. 1,339 pp. two volumes; $65.00 each.**

From the press release: This two-volume publication is the result of efforts by the Bureau of Land Management of the Department of the Interior, and the National Oceanic and Atmospheric Administration's Outer Continental Shelf Environmental Assessment Program. There are 73 chapters written by experts in their fields ... meant to be all-inclusive, to help build an understanding of how the Bering Sea functions as a system ....

***The Geomorphology of the Great Barrier Reef: Quaternary Development of Coral Reefs* by David Hopley. 1982. John Wiley & Sons, New York, N.Y. 453 pp. $59.95.**

This book has a five-fold division, covering: the philosophical and physical environments of current research on the Great Barrier Reef; the major processes that operate on all reefs; longer term geomorphological evolution; the resulting morphology of modern reefs; and a brief examination of the influences on reef development, comparing the morphology of the Great Barrier Reef with that of other reef systems.

Sports and Hobbies

***The TFH Book of Tropical Aquariums* by Herbert R. Axelrod. 1982. TFH Publications, Inc., Ltd., the British Crown Colony of Hong Kong. 93 pp. $6.95.**

From the jacket: This ... book is perfect for anyone beginning with a freshwater tropical fish aquarium, because it covers all topics of significance to beginners .... The book is illustrated with ... full-color photos that ... serve as highly useful identification guides.

***The TFH Book of Marine Aquariums* by Warren E. Bergess. 1982. TFH Publications, Inc., Ltd., the British Crown Colony of Hong Kong. 93 pp. $6.95.**

This book is divided into two sections: one dealing with the principles of management underlying a successful saltwater aquarium in one's home, and one dealing with the types of creatures suitable for keeping.

Books Policy

Oceanus *welcomes books from publishers in the marine field. All those received will be listed and a few will be selected for review. Please address correspondence to Elizabeth Miller, editor of the book section.*

***A Field Guide to Coral Reefs* by Eugene H. Kaplan. 1982. A Peterson Field Guide Series book. Houghton Mifflin Co., Boston, Mass. 289 pp. $17.95.**

A complete pocket-sized guide to the reefs of the Caribbean and Florida. Provides information for identifying the common inhabitants of the reefs — fishes, shrimps, lobsters, crabs, molluscs, worms, sponges, jellyfish, sea anemones, comb jellies, and corals. Describes the ecology and biology of the reefs. More than 400 illustrations, 113 color photos.

***World Record Game Fishes,* M. B. McCracken, ed. 1982. The International Game Fish Association, Fort Lauderdale, Fla. 328 pp. $6.95.**

The latest world sportfishing records for more than 140 species of freshwater and saltwater fish. Ninety-seven pages of records in all-tackle, line class, and tippet class categories, accompanied by international angling regulations, world record requirements, and IGFA annual fishing contest rules. Also, articles by fishery scientists and fishermen, a "guide to fishes," a multilingual list of fishes' names, and illustrated instructions for tying knots used in fishing.

Books for Children

***The Sea Library,* six 32-page paperback books by Sue Beauregard and Jill Fairchild. 1982. Cypress Publishing Corp., Glendale, Calif. $3.75 each softcover; $7.95 each hardcover.**

The titles are: *Coral Reef Fish, Open Ocean Fish, Seabirds, Ocean Plants, Ocean Mammals,* and *Ocean Floor Animals.* Illustrated with color photographs, these books are written simply and concisely for children — but adults who read them to their kids are bound to learn something they did not already know about marine flora and fauna.

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General Issue, Vol. 23:2, Summer 1980 — A collection of articles on a range of topics including the dynamics of plankton distribution, submarine hydrothermal ore deposits, legal issues involved in drilling for oil on Georges Bank, and the study of hair-like cilia in marine organisms.

electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.

Sound in the Sea, Vol. 20:2, Spring 1977 — The use of acoustics in navigation and oceanography.

Issues not listed here, including those published prior to Spring 1977, are out of print. They are available on microfilm through University Microfilm International; 300 North Zeeb Road; Ann Arbor, MI 48106.

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Oceanus back issues

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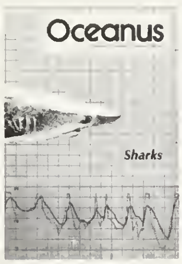

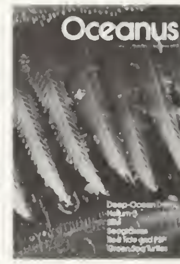

General Issue, Vol. 25:2, Summer 1982 — Contains articles on how Reagan Administration policies will affect coastal resource management, a promising new acoustic technique for measuring ocean processes, ocean hot springs research, planning aquaculture projects in the Third World, public response to a plan to bury high-level radioactive waste in the seabed, and a toxic marine organism that could prove useful in medical research.

Research Vessels, Vol. 25:1, Spring 1982 — Despite rising costs, ships continue to play a key role in marine science.

Sharks, Vol. 24:4, Winter 1981/82 — Shark species are more diverse and less aggressive than the "Jaws" image leads us to believe.

Oceanography from Space, Vol. 24:3, Fall 1981 — Satellites can make important contributions toward our understanding of the sea.

General Issue, Vol. 24:2, Summer 1981 — A wide variety of subjects is presented here, including the U.S. oceanographic experience in China, ventilation of aquatic plants, seabirds at sea, the origin of petroleum, the Panamanian sea-level canal, oil and gas exploration in the Gulf of Mexico, and the links between oceanography and prehistoric archaeology.

The Oceans as Waste Space?, Vol. 24:1, Spring 1981 — *Limited supply only.*

The Coast, Vol. 23:4, Winter 1980/81 — The science and politics of America's 80,000-mile shoreline.

Senses of the Sea, Vol. 23:3, Fall 1980 — A look at the complex sensory systems of marine animals.

General Issue, Vol. 23:2, Summer 1980 — A collection of articles on a range of topics including the dynamics of plankton distribution, submarine hydrothermal ore deposits, legal issues involved in drilling for oil on Georges Bank, and the study of hair-like cilia in marine organisms.

A Decade of Big Ocean Science, Vol. 23:1, Spring 1980 — As it has in other major branches of research, the team approach has become a powerful force in oceanography.

Ocean Energy, Vol. 22:4, Winter 1979/80 — How much new energy can the oceans supply as conventional resources diminish?

Ocean/Continent Boundaries, Vol. 22:3, Fall 1979 — Continental margins are being studied for oil and gas prospects as well as for plate tectonics data.

Oceans and Climate, Vol. 21:4, Fall 1978 — *Limited supply only.*

General Issue, Vol. 21:3, Summer 1978 — The lead article here looks at the future of deep-ocean drilling. Another piece, heavily illustrated with sharply focused micrographs, describes the role of the scanning electron microscope in marine science. Rounding out the issue are articles on helium isotopes, seagrasses, paralytic shellfish poisoning, and the green sea turtle of the Cayman Islands.

Marine Mammals, Vol. 21:2, Spring 1978 — Attitudes toward marine mammals are changing worldwide.

The Deep Sea, Vol. 21:1, Winter 1978 — Over the last decade, scientists have become increasingly interested in the deep waters and sediments of the abyss.

General Issue, Vol. 20:3, Summer 1977 — The controversial 200-mile limit constitutes a mini-theme in this issue, including its effect on U.S. fisheries, management plans within regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.

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